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THESIS

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ABSTRACT

To make comparisons to seven similar cruises, the geostrophic method of volume transport and velocity analysis was applied to ALAMINOS cruises 67-A-6 of 4 to 22 August 1967 and 68-A-2 of 13 February to 6 March 1968. An average velocity of 83 cm/sec and a volume transport of 27.5 Sverdrups was found in the Yucatan Channel in August and an average velocity of 79 cm/sec and a volume transport of 26.6 Sverdrups was found in the channel for February to March. A subsurface westward flow occurred in August along the southern coast of Cuba providing input into the Loop Current north of the Yucatan Channel. The Loop Current never crossed 25°N latitude. A cold ridge extended from the Florida shelf to the Campeche Bank.

An analysis of East-West volume transport in the central Gulf indicated a merging of east and west Gulf waters between 87°50'W and 89°30'W longitude for the MABEL TAYLOR cruise of 1932 and the ATLANTIS cruise of 1935. The GERONIMO cruise of February-March 1967 and cruise 68-A-2 indicated a merging of east and west Gulf waters between 89°30'W and 91°00'W longitude.

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I. INTRODUCTION

Emphasis on the study of the circulation in the Gulf of Mexico began about 1925. This interest was motivated by the apparent misconception that the circulation in the Gulf consisted of the Yucatan Current which entered the Gulf at the Yucatan Channel and flowed clockwise around the Gulf to exit at the Florida Straits as the Florida Current. Parr [1935] made a cruise in the Gulf on the MABEL TAYLOR in 1932, and found at that time (February to April) that a surface current entered the Gulf at the Yucatan Channel and flowed, without deviation, toward the Florida Straits. He also found that a subsurface flow in the current intruded into the eastern Gulf.

Since that time the Gulf has been studied extensively by numerous people. The water masses of the Gulf have been identified by their temperature and salinity relationship. Observations of the Loop Current have shown various patterns of flow. Detached eddies have been observed which were apparently once a part of the Loop Current. The Loop Current itself has intruded into the eastern and central Gulf as far north as 28°N latitude.

The definition of the Loop Current varies with authors. Nowlin and McLellan [1967] referred to the Loop Current as only that portion of the current in the Gulf, excluding the Yucatan Current and the Florida Current. However, since the Yucatan and Florida Currents are really part of the Loop Current, they have been included, in any reference in this paper, in the Loop Current.

The determination of the current patterns is not the only reason the Gulf has been studied so extensively. Pilot charts issued by the

Naval Oceanographic Offices have indicated that there is flow into the west Gulf with no apparent return. The east and west Gulfs are considered by some people to be isolated from each other. However, it has been shown that powerful eddies, which were once part of the Loop Current, have moved into the Gulf and dissipated, altering the water characteristics. This East-West exchange is important to the fishing industry because the change in water characteristics effects the environment in which fish live.

The extremities of the Loop Current can be generally located by a T-S diagram. Above 17°C, water on the right (looking downstream of the current) side of the current has a different T-S curve than the water on the left side of the current [Leipper 1970]. The water in between contains the Loop Current. Locations (extremities) can also be determined from the slope of the 22°C isotherm in the upper 200-300 meters of water.

The objective of this paper is to analyze the Loop Current, as observed by ALAMINOS cruises 67-A-6 of 4-22 August 1967, 68-A-2 of 15 February to 6 March 1968, 65-A-11 of 10-24 August 1965, 65-A-13 of 12-24 September 1965, and 66-A-15 of 27 October to 13 November 1966, and to analyze East-West volume transport in the Central Gulf. The results are presented so that they may assist future studies of the Loop Current and general current pattern in the Gulf of Mexico.

II. PROCEDURES

A. GEOSTROPHIC VELOCITY AND VOLUME TRANSPORT COMPUTATIONS

To compute the relative velocities and volume transports of geostrophic currents, the assumption is made that the pressure gradient acceleration and the coriolis acceleration are the only accelerations present and that they are equal in magnitude and opposite in direction. Friction is neglected. Under these assumptions it can be shown that the currents are normal to the slopes of isobaric surfaces which means the currents flow parallel to contour lines of dynamic height anomaly. The term relative is used since the currents are determined with respect to a reference level where some residual motion may exist.

The choice of a reference level is arbitrary but is usually taken where minimum motion seems to exist. In the eastern Gulf of Mexico, Hubertz [1967] chose 1350 meters as a reference level. Nowlin and McLellan [1967] state that a depth of 1000 meters may be chosen without introducing errors of much more than 10 cm/sec in current computations. In this study, partly because of this small error and partly because data were not regularly available at greater depth, a depth of 1000 meters was chosen as the reference level. All currents and volume transports were computed relative to it.

Appendix A has a numbered list of equations used for various computations of velocity and volume transport. Future reference to an equation by number will indicate an equation listed in this appendix.

Equation (1) provides a method of calculating volume transports between two stations, in a layer between the sea surface and a selected depth, assuming the selected depth to be a level of no motion. The

equation was used by Hewitt [1970] to determine volume transport in specific layers (e.g. 0-200 meters relative to the 200 meter surface). Schneider [1969] used the equation to determine the total volume transport between the sea surface and 1000 meters.

If the notation of Equation (1) is modified, it can be used to calculate volume transport in a given layer referred to a reference level, below that layer, at which no motion may be assumed to exist [Hubertz 1967]. The dynamic height anomaly (ΔD) is the summation of the dynamic height anomalies from the sea surface to the depth of the chosen reference level. The volume transport function (Q) is the difference between the summation of the transport functions at each depth from the sea surface to the top and the summation from the sea surface to the bottom of the layer of interest. The term (Z_r) is the difference in depth between the top and bottom of this layer. It is therefore possible to use data which was computed assuming the sea surface as the reference level to compute geostrophic volume transport and velocity relative to another reference level.

It was found that the use of Equation (1), with a chosen reference level, produced ambiguities in interpretation of the resulting signs (+ or -) of velocity and transport. Computed sea surface velocities indicated at times a flow in one direction, while computed volume transports indicated total volume transport in the opposite direction. To eliminate the ambiguity, Equations (2) and (3) were used to compute the increment of volume transport in the layers of water between the standard depths, relative to 1000 meters. This method permits complete analysis, by layers, of the entire column of water between two stations from the chosen reference level to the sea surface. It is of particular interest when the direction of volume transport is different at

different depths in the column due to a change in the direction of the slope of the isobaric surfaces. Cruises 68-A-2 and 67-A-6, as well as the remaining cruises conducted in the Gulf of Mexico series, were analyzed this way.

To determine the effect of possible motion (velocity) at the depth selected as the reference level for geostrophic volume transport, the column of water between stations 17 and 18 of cruise 68-A-2 was analyzed assuming velocities of 0, 5, and 10 cm/sec respectively at 1000 meters. These values were added to the velocities at each depth of calculation from 1000 meters to the sea surface, and the volume transports, in Sverdrups (Sv), were calculated for the various layers, 0-200 meters, 0-500 meters, and 0-1000 meters. The results are shown in Table I.

TABLE I

VOLUME TRANSPORT, RELATIVE TO 1000 METERS, FOR ASSUMED VELOCITIES AT 1000 METERS (Stations 17-18, Cruise 68-A-2)

Assumed Velocity (cm/sec)	0	5	10
LAYERS (m)	VOLUME TRANSPORT (Sv)	VOLUME TRANSPORT (Sv)	VOLUME TRANSPORT (Sv)
0-200	11.20	12.01	12.55
0-500	17.97	20.02	21.43
0-1000	20.82	24.91	27.78

Substitution of Equation (2) into Equation (3), Appendix A, indicated that the total geostrophic volume transport from the sea surface to the chosen reference level between station pairs was independent of

the distance between the station pairs, but was dependent only on the difference in dynamic heights of the sea surface relative to the chosen reference level. Station pairs with the same differences in dynamic heights of the sea surface, relative to the chosen reference level, will have the same total volume transport between the sea surface and the chosen reference level and the same volume transport error for a given velocity at the chosen reference level. The distribution of the volume transports by layers may differ for the different station pairs.

If, as Nowlin and McLellan state, the maximum error in velocity is about 10 cm/sec at the 1000 meter reference level, the maximum error in volume transport through 1000 meters for stations 17 and 18 is approximately 6 to 7 Sverdrups. This error is approximately 30 to 35 percent of the volume transport found when the assumed velocity is zero. The dynamic height difference of the sea surface, relative to 1000 meters, for station pair 17-18 of cruise 68-A-2 was 0.5 m^2/sec^2.

B. USE OF THERMAL STRUCTURE AND THE 22°C ISOTHERM TO LOCATE THE LOOP CURRENT AND DETERMINE ITS EXTREMITIES

Dynamic topography at various depths is used to locate and study, in detail, geostrophic currents at those depths. Unfortunately the location of currents can vary from day to day, making it very difficult to plan a cruise so that the positions of the hydrographic stations will cover satisfactorily any strong and variable (in position) current which is of interest. Other methods may be combined with dynamic topography analysis in order to more exactly locate a current.

Leipper [1970] utilized a method in which the thermal structure in the upper 300 meters of water locates a current. Leipper's analysis indicates that the 22°C isotherm is representative throughout the year

of the field of isotherms in the Loop Current in the Gulf of Mexico. Bathythermograph data taken across a strong current, such as the Loop Current, can present a good indication of its existence, location, and direction of flow. Hewitt [1970] adapted this method to determine the extremities of the Loop Current and major eddies in the Gulf of Mexico for cruises 65-A-11, 65-A-13, and 66-A-15 conducted by Leipper.

Figure 1 presents a section of bathythermograph data taken across the Loop Current for cruise 68-A-2. The slope of the 22°C isotherm between BT stations 70 and 80 indicates a current out of the paper as indicated by the symbol ⊙. A reversed slope would indicate flow into the paper indicated by the symbol ⊗. The point of maximum slope of the 22°C isotherm is a good indication of the location of the maximum velocity of the current, as indicated by Leipper.

Sections of bathythermograph data which crossed the strong currents were used to indicate the boundaries (extremities) of the current. The extremity of the current is assumed to have been reached when the general trend of the 22°C isotherm is reversed. Figure 1 is a good example of how this method of analysis is applied. It indicates a general trend of the slope of the 22°C isotherm between BT stations 70 and 80 to be up toward the sea surface. The trend of the slope is reversed for stations 68 to 70; therefore, the extremities of the current on the right of the dashed line are considered to be at stations 70 and 80.

Two problem areas arise when using the 22°C isotherm. First, this method of analysis is only applicable when strong currents exist. An attempt was made to correlate weaker currents and thermal structure, but the definite features of the thermal structure in Figure 1 were not indicated across the weaker current. Secondly, slight reversals in the slope of the 22°C isotherm were indicated even though the

obvious trend of the slope was in one specific direction. The location of the current was determined by the general trend of the slope of the $22^{\circ}C$ isotherm.

C. SHALLOW STATION ANALYSIS

A major problem was encountered computing volume transport and velocity for the portion of the current which passed over an area where the depth was less than the selected reference level (1000 meters). Geostrophic volume transport between a water surface and the chosen reference level and the geostrophic velocity of that water surface, relative to the chosen reference level, can only be calculated when the slope of that water surface, relative to the chosen reference level, is known. In order to compute the volume transport in an upper layer relative to a reference level below that layer, the dynamic height anomaly of the top and bottom of the layer, relative to the reference level, must therefore be known at two locations.

Fomin [1964] derived a method which is formulated by Equation (4), Appendix A. This equation enables the computation of a theoretical addition (Δ) to the dynamic height anomaly of the shallow station so that the shallow station can be compared to deep water stations in order to determine the geostrophic velocity of the sea surface relative to the chosen reference level, and the geostrophic volume transport between the sea surface and the chosen reference level.

Hewitt [1970] utilized another method of obtaining a useable dynamic height of the sea surface for a shallow water station. This method is based upon an apparent correlation of dynamic height of the sea surface, relative to 1000 m, versus the depth of the $22^{\circ}C$ isotherm. From the observed isotherm depth at a shallow station, the correlation

indicates the dynamic height the sea surface might have had if the depth of the station had been 1000 meters. Figure 2 indicated Hewitt's correlation curve and the correlation curve used for cruises 67-A-6 and 68-A-2. These curves represent a least-squares best fit to the observed data. The depth of the 18°C isotherm was used for cruise 68-A-2 because the 22°C isotherm was not present everywhere. This curve did not coincide with the curves for the depth of the 22°C isotherm. The slope at various points on the curves were calculated and compared, since the slopes should be nearly the same if the correlation is to be a good one. The slope of the curves for cruises 67-A-6 and 68-A-2 were very similar at all locations. Hewitt's curve and the curve for cruise 67-A-6 had similar slopes at shallow depths of the 22°C isotherm, but for a small portion of the curves at the deepest depths, the slopes differed. This difference in slope could cause a maximum difference of 1.25 m^2/sec^2 in the selected dynamic height at a depth of 200 meters. This is a large difference and indicates that the value of such a curve as a means of determining the dynamic height of the sea surface depends on how much the observed data varies from the curve.

Fomin's method was used when the shallow station was a hydrographic station, but it did not seem to be applicable when the depth of the shallow station was very shallow compared to the deep station. For cruise 68-A-2 the depth of the station at the western extremity of the Loop Current in the Yucatan Strait was 30 meters, and the depth at the station at the eastern extremity was 1000 meters. Fomin's method provided current velocities and volume transports which were considered too large to be reasonable when compared to the velocities and volume transports farther north in the same current. The 22°C isotherm

correlation method was used both in this case and for the case of the shallow BT station.

After computing volume transport involving a shallow station, another problem presented itself. The computed volume transport was analyzed for two stations as though their depths had been 1000 meters. However, the actual depth between the stations was, in places, less than 1000 meters, so the computed volume transport was too large. To determine what fraction of the computed volume transport was actual volume transport, a plot of depth versus distance between stations was made. This plot provided an estimate of the areal extent of the water in the cross-section. The estimated area divided by the entire rectangular area between the two stations was multiplied by the computed volume transport to obtain an approximation of the actual volume transport.

These methods are not the only ways of analyzing a shallow water station. Fomin's method is only one of the methods he presented. Nowlin and McLellan [1967] used a method of extrapolation of the dynamic height anomaly for the shallow station from the dynamic height anomalies for the two closest deep stations. The method used depended on the data available and the depth of the station. Hydrographic data were used as much as possible, but such data were not always available.

III. CRUISE 68-A-2

A. GENERAL

Cruise 68-A-2 was planned and conducted by Leipper [1968] from 13 February to 6 March 1968. This cruise was one of a series of eight conducted from 1965-1968 to study the temperature-depth structure of the Gulf of Mexico in the summer and winter seasons. This particular one was also planned to study the East-West volume transport across the central Gulf. Figure 3 indicates three full North-South legs of the cruise across the deep Gulf which were made to accomplish this purpose.

Figures 4, 5, and 6 present the contours of dynamic topography for the surface, 200 meters, and 500 meters, relative to 1000 meters, the selected reference level. Using STD and BT data and the dynamic height contour charts, the location, geostrophic volume transport and velocity of the Loop Current were established. An analysis of the geostrophic volume transport in the Gulf across Legs I, II, and III was also made.

The Loop Current entered the Gulf through the western side of the Yucatan Channel between stations 24 and 30. It intruded into the Gulf 369 km (from the western tip of Cuba to the outer extremity of the current) before it turned eastward. This northward intrusion is approximately 131 km less than that found by Nowlin and McLellan [1967] in their analysis of cruise 62-H-3 of 12 February to 31 March 1962. However, the extent of the intrusion of the current was observed by Nowlin and McLellan on the second or third of March, while the extent of the intrusion found for cruise 68-A-2 was observed on 19 February. Since the northward extent of the intrusion may be increasing at this time

of year, the approximately 10 days difference in observation times may explain, in part, the difference in the extent of the intrusion, as observed on the two cruises. Leipper [1970] found indication that the intrusion increases about 150 km per month, during mid-February to late March. At this rate, the 10 days difference in time would allow the intrusion for cruise 68-A-2 to advance approximately 48 km farther into the Gulf. It is also possible that the full extent of the intrusion for cruise 68-A-2 was not observed because the northern end of the Loop Current was not adequately covered by hydrographic stations.

Figure 7 indicates the location of the extremities (dashed lines) and the location of the maximum current velocity (solid lines) across the two sections A and B. These two sections represent the only two crossings of the Loop Current made during cruise 68-A-2.

The upper waters were so cold during cruise 68-A-2 that the 22°C isotherm was not present. A study of BT data indicated that the 18°C isotherm was a good substitute for the 22°C isotherm as an indicator of current location, thus a plot of the depth of the 18°C isotherm versus the dynamic height anomaly of the sea surface relative to 1000 meters was used to infer dynamic topography for analysis of shallow water BT stations. The observed data for the cruise varied very little from the correlation curve. There was a lack of stations with sea surface dynamic heights (relative to 1000 meters) of 1.3-1.6 m^2/sec^2 because these dynamic heights were representative of the Loop Current, and for this cruise there were very few stations in the narrow Loop Current. However, the correlation of the depth of the 18°C isotherm and dynamic height of the sea surface was considered good for this cruise.

The Loop Current was 137 km wide, measured between extremities, as it entered the Gulf at section A, Figure 7. The maximum sea surface velocity was located over the 300 meter isobath, as was also found by Nowlin and McLellan [1967]. Methods described previously were used to determine the current's location, velocity, and transport involving the stations of limited depth on the western side of the current. The width of the current increased to the north, becoming 172 km, from extremity to extremity, at section B where it turned eastward.

B. VELOCITIES

Table II shows sea surface velocities computed for the Loop Current at sections A and B.

TABLE II

SEA SURFACE GEOSTROPHIC VELOCITIES OF THE LOOP CURRENT RELATIVE TO 1000 METERS (Cruise 68-A-2)

CROSS-SECTIONS	SECTION * EXTREMITIES	AVERAGE VELOCITY (cm/sec)	MAXIMUM VELOCITY (cm/sec)
A	24-80 (BT, S)	79.2	91.3
B	17-20	68.3	119.1

*Note: BT-Bathythermograph station

S-Shallow station

The average sea surface velocities were computed from the velocities of the sea surface (relative to 1000 meters) between pairs of stations along the cross-section of the Loop Current. The sea surface velocities for each station pair were added together and then averaged. The maximum

surface velocity (referred to 1000 meters) increased as the current proceeded northward; however, the average velocity of the current decreased, probably because of the broadening of the current.

Figure 4 indicates an apparent anti-cyclonic eddy in the western Gulf centered at 24°30'N, 93°42'W. The southern half of the eddy was not observed during the cruise. The sea surface velocity of the observed portion of the eddy reached a maximum of 21 cm/sec between stations 89 and 90.

C. VOLUME TRANSPORT

Volume transport across sections A and B for cruise 68-A-2 were computed for layers of, 0-200 meters, 0-500 meters, and 0-1000 meters (all referred to 1000 meters) when the hydrographic stations were in deep water (1000 meters or greater).

Table III indicates the volume transports calculated for both cross-sections.

TABLE III

LOOP CURRENT GEOSTROPHIC VOLUME TRANSPORTS RELATIVE TO 1000 METERS (Cruise 68-A-2)

CROSS-SECTION	STATION PAIRS *	0-200 m (Sv)	0-500 m (Sv)	0-1000 m (Sv)
A	24-25	6.4	10.7	13.2
	25-80(S,BT)	-	-	13.4
	17-18	11.2	18.0	20.8
B	18-19	6.7	12.1	14.4
	19-20	2.3	5.0	7.1

*Note: S-Shallow water station

BT-Bathythermograph station

The volume transport across section A (0-1000 meters) is 26.6 Sv. Since the majority of the depths are less than 300 meters, the greatest part of the volume transport between stations 25 and 80 (BT) was in shallow water. Therefore, the largest portion of the volume transport through section A was probably in the upper 200 meters of water. Section B had a volume transport of 42.3 Sv in the 0-1000 meter layer. Table III indicates that 20.2 Sv occurred in the layer of 0-200 meters, while 14.9 Sv occurred in the layer of 200-500 meters. Only 7.2 Sv occurred in the layer of 500-1000 meters. Therefore, the 0-200 meter layer had more volume transport than either of the layers below it.

The increase in volume transport of 15.7 Sv at section B over section A seems to have come from the west across the Campeche Bank and from the area north of Cuba. The analysis of volume transport between stations 25 and 38 is indicated in Table IV. All of the transports are to the east and the calculations assume a depth of greater than 1000 meters.

TABLE IV

GEOSTROPHIC VOLUME TRANSPORT, RELATIVE TO 1000 METERS, BETWEEN STATIONS 25 AND 38 (Cruise 68-A-2)

LAYER	TRANSPORT (Sv)
0-200 m	10.2
0-500 m	16.6
0-1000 m	18.8

The bottom topography of the cross-section between station 25 and 38 decreases to a minimum depth of approximately 500 meters, and all the water approaching the cross-section between the stations, from the west and south, comes across the Campeche Bank or through the Yucatan Channel. Figure 4, the dynamic topography of the sea surface relative to 1000 meters, indicates that the water movement in the southern part of the Gulf, between latitudes 22°N to 24°N and longitudes 88°W to 91°W, is generally toward the east. Also, the analysis of the North-South legs of the cruise indicated eastward volume transport in this area.

Although the water is shallow (less than 1000 meters) between stations 25 and 38, the computed volume transport in the upper 500 meters of water should be fairly indicative of total transport. The volume transport (16.6 Sv) in this layer accounts for approximately 88 percent of the total volume transport between the two stations.

A portion of the volume transport between stations 25 and 38, included that of the Loop Current, so only a portion of the volume transport could be considered as an input into the current. The difference of 15.7 Sv probably consisted partially of an input from the western Gulf caused by eastward flow over the Campeche Bank. An analysis of stations 20 to 24, which lie to the east of the Loop Current and north of section A (see Figure 3), indicated a net (0-1000 meters) volume transport of 8.3 Sv to the west. This indicated flow may have been another input into the Yucatan leg of the Loop Current caused by flow to the west along the northern coast of Cuba and flow toward the northwest along the southern coast of Cuba.

The fact that the largest portion of the volume transport generally occurred in the upper 200 meters of water was also supported by the

velocity analysis (at different depths) with respect to 1000 meters. At all times the velocities at; 0m (surface), 10m, 20m, 30m, 40m, 50m, etc. decreased with depth. The higher velocities occurred in the upper 100 meters and water velocity decreased rapidly between 100 and 1000 meters.

D. EAST-WEST VOLUME TRANSPORT IN THE CENTRAL GULF

There have been differing thoughts concerning the possible connection between the east and west Gulf waters. In the winter these waters seem to be connected either by direct flow or by large detached eddies which have originated from the strong Loop Current. Leipper made three North-South legs during cruise 68-A-2 along longitudes $87^{o}50'W$, $89^{o}30'W$, and $91^{o}00'W$ respectively. The succeeding pages contain an analysis of the East-West volume transports and the velocities of selected water surfaces between the deep water stations only, although data were also taken at shallow water stations.

Figure 3 indicates the three North-South legs in their entirety. Leg I includes the segments between deep stations 38-43 and 47-49. Leg II includes the segment between deep stations 61-68. Leg III includes the segments between deep stations 74-79 and 82-83. Eastward transport is indicated by a double line and westward transport (for deep stations) by a single line. The eastward flow across the indicated southern portions of each leg seemed to correlate well with the cyclonic eddy indicated on Figure 4 centered in the eastern Gulf and extending across the central Gulf.

Tables V, VI, and VII indicate net geostrophic volume transport and its direction in the indicated layers for pairs of hydrographic stations for cruise 68-A-2.

TABLE V

CENTRAL GULF EAST-WEST GEOSTROPHIC VOLUME TRANSPORT, VELOCITY, AND DIRECTION RELATIVE TO 1000 METERS - LEG I (Cruise 68-A-2)

STATION PAIRS	LAYERS (m)	TRANSPORT (Sv)	VELOCITY (cm/sec) *	DIRECTION *
38-39	0-200	1.0	4.4	E
	0-500	1.8	3.8	E
	0-1000	2.3	14.6	E
39-40	0-200	2.4	16.7	E
	0-500	5.2	7.0	E
	0-1000	6.2	15.9	E
40-41	0-200	1.7	26.0	W
	0-500	4.5	14.4	W
	0-1000	5.7	13.6	W
41-42	0-200	3.4	17.0	W
	0-500	5.7	7.5	W
	0-1000	6.8	27.7	W
42-43	0-200	0.4	1.0	E
	0-500	0.7	1.5	E
	0-1000	0.9	2.8	E
43-48	0-200	1.0	2.8	E
	0-500	1.4	0.1	E
	0-1000	1.4	5.5	E
48-49	0-200	0.5	3.1	W
	0-500	0.8	1.4	W
	0-1000	1.1	4.7	W

*Note: E-East
W-West

The velocities for the 0-200 and 0-500 meter layers are those of the bottom of the layers. The velocity for the 0-1000 meter layer is that of the sea surface.

TABLE VI

CENTRAL GULF EAST-WEST GEOSTROPHIC VOLUME TRANSPORT, VELOCITY, AND DIRECTION RELATIVE TO 1000 METERS - LEG II (Cruise 68-A-2)				
STATION PAIRS	LAYERS (m)	TRANSPORT (Sv)	VELOCITY (cm/sec) *	DIRECTION *
61-63	0-200 0-500 0-1000	3.8 7.1 8.7	20.8 10.0 28.6	E E E
63-64	0-200 0-500 0-1000	2.8 5.4 6.6	14.5 7.2 19.5	W W W
64-65	0-200 0-500 0-1000	2.0 3.5 4.2	11.0 4.6 17.6	W W W
65-66	0-200 0-500 0-1000	0.8 1.8 2.2	6.0 3.5 3.0	W W W
66-67	0-200 0-500 0-1000	0.7 1.2 1.5	3.3 1.8 3.1	W W W
67-68	0-200 0-500 0-1000	1.1 2.3 3.0	6.9 4.4 6.7	E E E

*Note: E-East
W-West

The velocities for the 0-200 and 0-500 meter layers are those of the bottom of the layer. The velocity for the 0-1000 meter layer is that of the sea surface.

TABLE VII

CENTRAL GULF EAST-WEST GEOSTROPHIC VOLUME TRANSPORT, VELOCITY, AND DIRECTION RELATIVE TO 1000 METERS - LEG III (Cruise 68-A-2)				
STATION PAIRS	LAYER (m)	TRANSPORT (Sv)	VELOCITY (cm/sec) *	DIRECTION *
74-75	0-200 0-500 0-1000	1.3 1.3 1.2	1.6 -0.2** 15.3	E E E
75-76	0-200 0-500 0-1000	0.7 1.4 1.6	4.9 2.0 5.8	E E E
76-77	0-200 0-500 0-1000	0.5 1.2 1.4	4.7 2.5 1.2	W W W
77-78	0-200 0-500 0-1000	0.2 0.5 0.7	1.0 1.2 5.2	W W W
78-79	0-200 0-500 0-1000	0.4 0.5 0.5	1.2 0.2 4.5	W W W
79-83	0-200 0-500 0-1000	1.9 2.8 3.2	5.6 2.7 20.9	E E E
82-83	0-200 0-500 0-1000	0.3 0.5 0.7	0.5 1.1 3.0	W W W

*Note: E-East
W-West

The velocities for the 0-200 and 0-500 meter layers are those of the bottom of the layers. The velocity for the 0-1000 meter layer is that of the sea surface.

**The negative sign for the velocity of the 500 meter surface for station pair 74-75 represents a reversal in flow.

Station pairs 74-75 and 78-79 of Leg III were the only station pairs where there was a reversal in the direction of flow between the surface and 1000 meters. These reversals of flow account for the fact that there was greater flow in the 0-200 and 0-500 meter layers than in the 0-1000 meter layer for station pair 74-75 and that station pair 78-79 had no net flow from 500-1000 meters. In both cases, flow in the deeper water was in the opposite direction of the surface waters, but the magnitude of the flow was less than that of the surface layers.

To analyze East-West transport, the net volume transport and direction in the layer from 0-1000 meters was used. Table VIII indicates the total volume transport in the east and west direction and the net volume transport and direction across each leg.

TABLE VIII

NET EAST-WEST DEEP WATER GEOSTROPHIC VOLUME TRANSPORT AND DIRECTION, RELATIVE TO 1000 METERS, ACROSS LEGS I, II, AND III (Cruise 68-A-2)

LEG	WEST TRANSPORT (Sv)	EAST TRANSPORT (Sv)	NET TRANSPORT (Sv) AND DIRECTION
I	13.6	10.8	2.8 West
II	14.5	11.7	2.8 West
III	3.3	6.0	2.7 East

To analyze for volume continuity, the area enclosed by Legs I and II and lines drawn from stations 49 to 61 and 38 to 68 will be called area X, and the area enclosed by Legs II and III and lines drawn from stations 68 to 74 and 61 to 82, area Y (see Figure 3). Table IX

indicates the total volume transport inputs and outputs across the boundaries of these areas. Since the northern and southern boundaries represent the beginning of shallow water (less than 1000 meters), inputs across these boundaries represent flow from shallow to deep water and output represents flow from deep to shallow water.

TABLE IX

NET GEOSTROPHIC VOLUME TRANSPORT INPUTS AND OUTPUTS TO AREAS X AND Y, RELATIVE TO 1000 METERS (Cruise 68-A-2)

AREA	BOUNDARY	TRANSPORT (Sv)
X	Leg I	2.8 Input
	Leg II	2.8 Output
	STATIONS 49-61	2.0 Input
	STATIONS 38-68	2.9 Output
Y	Leg II	2.8 Input
	Leg III	2.7 Input
	STATIONS 68-74	0.6 Output
	STATIONS 61-82	4.3 Output

These calculations indicate a deficit of 0.9 Sv in area X and a 0.6 Sv excess in area Y. These apparent imbalances may have been caused by motion of the 1000 meter surface.

Area Y was the apparent meeting place for east and west Gulf waters. The majority of the water in area Y apparently flowed north between stations 61 and 82.

In an attempt to compare the East-West volume transport of this cruise with that of previous winter cruises, the positions of the hydrographic stations of Legs I, II, and III were replotted on available analyses of the depth of the 22°C isotherm for the following cruises: the MABEL TAYLOR cruise of 8 February-27 April 1932; the ATLANTIS cruise of 15 February-13 April 1935; and the GERONIMO cruise of 21 February-31 March 1967. Using the available 22°C isotherm topography provided a simple method of obtaining volume transport. Also, since the MABEL TAYLOR cruise had no unprotected thermometers for accurate depth determination, this method provided a means of calculating volume transport for the cruise.

Comparison of the selected cruises was made by selecting the depth of the 22°C isotherm for the replotted hydrographic stations. The dynamic height anomaly for each station was determined by using Hewitt's curve (Figure 2) for the correlation of the depth of the 22°C isotherm versus the dynamic height anomaly of the sea surface, relative to 1000 meters. As discussed previously, this method of determining the dynamic height anomaly permitted the calculation of volume transport, between stations, only for the column of water from the water surface to 1000 meters, relative to 1000 meters.

The 22°C isotherm was not present at all stations for the cruises because of the cold water. Stations 47 to 49 of Leg I, located on the northern part of the leg, could not be used for any cruise because of the absence of the 22°C isotherm.

Tables X and XI indicate the results of this analysis. The stations analyzed for each leg are indicated in the tables.

TABLE X

NET EAST-WEST DEEP WATER GEOSTROPHIC VOLUME TRANSPORT AND DIRECTION, RELATIVE TO 1000 METERS, ACROSS LEGS I, II, AND III FOR SELECTED WINTER CRUISES			
LEG	MABEL TAYLOR (1932)*	ATLANTIS (1935)*	GERONIMO (1967)*
I	13.2 Sv (E) (Stations 38-41)	15.8 Sv (E) (Stations 38-43)	1.0 Sv (W) (Stations 38-43)
II	13.8 Sv (W) (Stations 61-67)	18.6 Sv (W) (Stations 61-68)	1.7 Sv (W) (Stations 61-68)
III	4.4 Sv (W) (Stations 74-82)	7.8 Sv (W) (Stations 74-82)	16.8 Sv (E) (Stations 74-82)

*Note: E-East
W-West

An analysis of volume transport continuity for areas X and Y (see Figure 3) was also made using boundaries which include only those stations where the 22°C isotherm was present. Table XI indicates the results.

The apparent imbalances varied from 0.1 Sv to 2.9 Sv. This error may again have been caused by motion of the 1000 meter surface, use of a correlation curve which was not obtained from data for each specific cruise, or by misinterpretation of the value chosen for the depth of the 22°C isotherm as compared to its actual depth. The latter reason was probably the cause of the large imbalance of 2.9 Sv. However, the method of analysis, use of the depth of the 22°C isotherm, seemed to provide a good indication of the volume transport for the selected cruises.

TABLE XI

NET GEOSTROPHIC VOLUME TRANSPORT INPUTS AND OUTPUTS TO AREAS X AND Y, RELATIVE TO 1000 METERS, FOR SELECTED WINTER CRUISES

AREA	CRUISE	BOUNDARY	TRANSPORT (Sv)
X	MABEL TAYLOR (1932)	Leg I (Sta. 38-41)	13.2 Output
		Leg II (Sta. 61-67)	13.8 Output
		STATIONS 41-61	12.8 Input
		STATIONS 38-67	13.2 Input
	ATLANTIS (1935)	Leg I (Sta. 38-43)	15.8 Output
		Leg II (Sta. 61-68)	18.6 Output
		STATIONS 43-61	21.5 Input
		STATIONS 38-68	13.4 Input
	GERONIMO (1967)	Leg I (Sta. 38-43)	1.0 Input
		Leg II (Sta. 61-68)	1.7 Output
		STATIONS 43-61	4.4 Output
		STATIONS 38-68	5.0 Input
Y	MABEL TAYLOR (1932)	Leg II (Sta. 61-67)	13.8 Input
		Leg III (Sta. 74-82)	4.4 Output
		STATIONS 67-74	0.0
		STATIONS 61-82	8.2 Output
	ATLANTIS (1935)	Leg II (Sta. 61-68)	18.6 Input
		Leg III (Sta. 74-82)	7.8 Output
		STATIONS 68-74	3.5 Output
		STATIONS 61-82	4.4 Output
	GERONIMO (1967)	Leg II (Sta. 61-68)	1.7 Input
		Leg III (Sta. 74-82)	16.8 Input
		STATIONS 68-74	18.2 Output
		STATIONS 61-82	0.7 Output

Use of the $22^{\circ}C$ isotherm topography indicated that the Loop Current and a large anti-cyclonic eddy in the central Gulf provided the large inputs into the northern and southern boundaries of area X for the MABEL TAYLOR cruise. The Loop Current apparently split in this area. Part of it flowed west and was the driving force for the anti-cyclonic eddy, and part of it turned eastward eventually turning toward the Florida Straits. A similar circulation pattern existed for the GERONIMO cruise, but the eddy did not provide input into the northern boundary of area X.

An approximation of the volume transport input into the Gulf through the Yucatan Channel was made for all three cruises. The volume transports for the MABEL TAYLOR and GERONIMO cruises were 24.6 Sv and 26.5 Sv respectively. These values correspond closely to the 26.6 Sv calculated for cruise 68-A-2. The volume transport for the ATLANTIS cruise was 39.5 Sv.

Area X was the apparent meeting place of the water from the east and west Gulf for the MABEL TAYLOR and ATLANTIS cruises. The GERONIMO cruise and cruise 68-A-2 indicated area Y as the meeting place.

IV. CRUISE 67-A-6

A. GENERAL

Cruise 67-A-6 was conducted from 4 August to 22 August 1967 by Leipper [1968]. The cruise lasted 18 days, permitting only limited coverage of the Loop Current. Figure 8 shows the cruise stations. Five legs of the cruise crossed the Loop Current providing a good indication of its location. Figures 9, 10, and 11 present the dynamic topography (relative to 1000 meters) of the sea surface, 200 meter and 500 meter surfaces respectively. The locations of the extremities of the current, as determined by bathythermograph data and dynamic topography analysis, are indicated on Figure 12. The extremities of the current are indicated by dashed lines and the location of the maximum current is indicated by the solid line.

The dynamic topography for the surface (Figure 9), relative to 1000 meters, indicates a well defined anti-cyclonic eddy at $24^{o}24'$N, $88^{o}55'$W. The southern portion of the eddy had apparently moved on to the Campeche Bank. Figure 9 also indicated an anti-cyclonic eddy associated within the Loop Current whose flow apparently provided some water which flowed west along the northern coast of Cuba and returned to the Yucatan Channel as a southern current. Cruise station 60 was not useable for this analysis because of obvious errors in recorded salinities and temperatures at the standard depths from 500-1000 meters. Station 62 did not have any data for the water surface, so it was assumed that the dynamic height anomaly at the surface was the same as that for 10 meters.

Analysis of the water between stations 61 and 62 indicated that the surface layers of water (0-100 meters) and the water from 400-1000 meters did flow south while the water layers from 100-400 meters flowed north. The net transport (0-1000 meters), referred to 1000 meters, was only 0.2 Sv to the south. However, the maximum current (5.6 cm/sec) in the entire column of water was found at 200 meters flowing to the north. A section between stations 59 and 61 also indicated flow to the southeast in the water layers from the surface to 250 meters with a maximum velocity of 35 cm/sec at 100 meters (referred to 1000 meters). The layers below 250 meters down to 800 meters indicated weak flow to the northwest. A subsurface current to the west along the southern coast of Cuba was also found by Gordon [1967]. Therefore, there was probably some contribution to the Loop Current north of section A (Figure 12) from subsurface flow to the northwest near the western tip of Cuba.

The Loop Current crossings were labeled A through E, as indicated by Figure 12. The current entered the Gulf flowing to the north, it turned northeast toward Florida, and as it reached the 3000 meter depth contour it turned sharply to the southeast toward the Florida Straits. Its outer extremity intruded into the Gulf 342 km from the western tip of Cuba.

Analysis of section A indicated a broad Loop Current (from extremity to extremity). The sections between hydrographic stations 62, 63, and 64 only had an average sea surface velocity of 44 cm/sec and a maximum sea surface velocity of 47 cm/sec located between stations 63 and 64. The BT cross-section indicated a maximum velocity close to station 63. However, Fomin's analysis of a shallow water hydrographic station, used for station 65 on the western extremity of the Loop Current, indicated

a maximum sea surface velocity of 161 cm/sec between stations 64 and 65 flowing over the shallow bottom near the eastern coast of the Yucatan Peninsula. This maximum was probably influenced by the funneling of water between the Yucatan Peninsula and Cozumel Island. Cochrane [1962] indicated that the maximum current velocity was within an interval of 72 to 108 km north of Cozumel Island which is approximately the location of section A.

The largest portion of the total volume transport, relative to 1000 meters, in the Loop Current was in the upper 200 meters of water. With the exception of the shallow water stations where the volume transport in the upper layers could not be calculated, all but one station pair indicated a greater transport in the 0-200 meter layer than in the 200-500 meter or the 500-1000 meter layers (see Table XIII).

The analysis of section B was difficult because the depth of the 22°C isotherm at that section varied so much in such short distances that use of BT stations and the plot of the depth of the 22°C isotherm versus the dynamic height anomaly for the surface relative to 1000 meters was not practical. A small error in station location would have produced significant errors in the value of the dynamic height anomaly. Calculations were made utilizing only hydrographic station data.

B. VELOCITIES

Table XII indicates the maximum sea surface current velocity and the average sea surface velocity found at sections A through E.

The current broadened as it cleared the Campeche Bank and turned to the northeast between sections B and C. This broadening probably accounts for some of the decrease in the average velocity as the

TABLE XII

LOOP CURRENT SEA SURFACE VELOCITIES RELATIVE TO 1000 METERS (Cruise 67-A-6)			
CROSS-SECTION	SECTION EXTREMITIES *	AVERAGE VELOCITY (cm/sec)	MAXIMUM VELOCITY (cm/sec)
A	62-65 (S)	83.1	161.0
B	78-159 (BT)	101.1	107.0
C	52-55	74.4	122.5
D	91-95	58.9	98.9
E	89-183 (BT)	50.1	60.8

*Note: S-Shallow water station

BT-Bathythermograph station

current moved toward the Florida Straits. At section E the current narrowed again, but the average velocity still decreased. The indicated decrease is probably due to the fact that the northern portion of the cruise crossing at section E crossed the current at an oblique angle, and the geostrophic velocity components, being perpendicular to a line between stations, are not representative of the actual Loop Current velocity. The "Volume Transport" section of this cruise indicates a large increase in geostrophic volume transport at section E as compared to sections C and D. The cross-sectional area at section E decreased as compared to sections C and D. To permit an increase in volume transport and a decrease in cross-sectional area, the velocity must have increased. Assuming that the northern portion of cross-section E had crossed the Loop Current at a right angle, it was

calculated that the average velocity would have been 83 cm/sec and the maximum velocity would have increased to 105 cm/sec. These values are considered more indicative of the velocities of the Loop Current at section E than the values indicated in Table XII.

The section of the eddy indicated on Figure 12 at 24°24'N, 88°55'W was located over deep water (greater than 1000 meters). The maximum velocity of this section was 76 cm/sec and the average velocity was 54 cm/sec. Figure 9 indicates that water from the western Gulf flows eastward around the eddy over deep water and then returns to the western Gulf over the Campeche Bank. It is probable that some of this water continued into the eastern Gulf and became part of the Loop Current, providing an exchange of water from the western to the eastern Gulf.

C. VOLUME TRANSPORT

Table XIII indicates the volume transports calculated for layers of 0-200, 0-500, and 0-1000 meters with respect to 1000 meters. Shallow water analysis was used for sections A, B, and E.

To analyze volume transport continuity, the entire water column from 0-1000 meters was used. This presented an overall view of the volume transport in the Loop Current as the current proceeded from the Yucatan Channel to the area approximately 198 km west of the Florida Straits (Section E).

A net volume transport of 27.5 Sv crossed section A (Figure 12) with the majority of the water flowing across the section in the upper 200 meters of water. At section B, 34.9 Sv crossed the section. Station pair 77-75 of this section (Table XIII) indicates volume transports in the layers 0-200 and 0-500 meters, relative to 200 meters

TABLE XIII

LOOP CURRENT GEOSTROPHIC VOLUME TRANSPORT RELATIVE TO 1000 METERS (Cruise 67-A-6)				
CROSS SECTION	STATION PAIRS *	0-200 m (Sv)	0-500 m (Sv)	0-1000 m (Sv)
A	62-63	4.0	6.5	8.2
	63-64	4.0	7.4	10.3
	64-65 (S)	-	-	9.0
B	77-78	7.0	12.5	15.9
	77-75	(2.7)***	(10.0)***	19.0
C	52-53	10.0	16.2	19.3
	53-54	3.2	6.0	7.4
	54-55	0.3	1.2	1.3
D	91-92	4.4	7.1	7.9
	92-94	1.5	0.2	-0.3**
	94-95	9.6	17.1	20.6
E	88-89	5.8	10.4	12.7
	88-183 (S,BT)	(4.6)***	(16.5)***	17.0

*Note: S-Shallow water station
BT-Bathythermograph station

**Note: The minus sign indicates the volume transport in the opposite direction.

***Note: The numbers in parentheses are the volume transports in the layer relative to the bottom of the layer.

and 500 meters respectively. These volume transports were calculated relative to the bottom of the layer because the stations were in shallow water and because the values indicate which layer had the greatest volume transport. Volume transport for the 0-1000 meter layer for station pair 77-75 was calculated by computing the volume transport from hydrographic data for the water surface to 800 meters (referred to 800 meters) between stations 77 and 76 and then, assuming that a similar volume transport from 800-1000 meters as computed between stations 76 and 78 also flowed between stations 76 and 77, an additional 0.5 Sv was added. To this value was added 0.8 Sv, estimated from shallow water calculations between stations 75 and 76. The increase of volume transport from section A to B is probably due to the westwardly subsurface flow along the southern coast of Cuba and by a possible input from the anti-cyclonic eddy north of Cuba.

At section C there was a decrease in volume transport of 6.9 Sv as compared to section B. It was found that approximately 5 Sv passed between stations 51 and 52 (see Figure 8). These stations are located adjacent to the northwest extremity of the Loop Current at section C. This water was probably lost by the current as the current turned eastward. Nowlin and McLellan [1970] indicated that there was a loss from the Loop Current in the region of the northern Campeche Bank due to an apparent branching off to the west of part of the current. Stations 98 and 99 indicated a flow to the northwest which may have been caused by the branching off of the Loop Current. Therefore, the difference in volume transport of 6.9 may be accounted for, at least in part, by the losses due to the turning and possible branching off of the current.

Section D indicates an increase of 0.5 Sv in volume transport as compared to section C. Figure 9 indicates a cyclonic eddy to the north of section D. The increase in volume transport of the Loop Current at section D was probably due to the entrainment of water circulation from around this eddy. The negative sign for the volume transport in the 0-1000 meter layer for stations 92 and 94 of this section was due to a volume transport to the west in the layer from 200 to 700 meters below the surface. This westward volume transport of 1.8 Sv, between these two depths, provided a net westward volume transport of 0.3 Sv in the layer from the surface to 1000 meters, relative to 1000 meters. BT data for section D did not indicate a reversal in current direction because the reversal occurred below 200 meters. The magnitude of the velocity component at the sea surface, relative to 1000 meters, was 18 cm/sec between stations 92 and 94, which is considered low for the Loop Current. However, the magnitudes of the velocities components between stations 91 and 92 and stations 94 and 95 were 59 cm/sec and 99 cm/sec respectively. This indicates that stations 92 and 94 were probably in the Loop Current in spite of the low velocity.

As the current approached the Florida Straits, the volume transport increased to 29.7 Sv at section E. The increase was probably caused by entrainment of water from the Florida shelf. However, there was no data available to verify southward flow over the shelf.

The apparent difference of 2.2 Sv in volume transport into the Gulf by the Loop Current and that approaching the Florida Straits was probably due to the southwestward flow around the anti-cyclonic eddy just north of Cuba.

The volume transport across a section of the anti-cyclonic eddy north of the Yucatan Peninsula was 21.3 Sv between stations 105 and 231 (BT). This is of significant magnitude and indicates that the eddy contained a strong current and may have become detached from the Loop Current.

V. COMPARISON OF CRUISES 67-A-6 AND 68-A-2

Cruise 67-A-6 was conducted during the late summer of 1967 and cruise 68-A-2 was conducted late during the following winter. A comparison of these cruises (Figures 3-11) gave a good indication of what changes in water circulation occurred primarily to the Loop Current, during the fall and early winter.

The Loop Current entered the Gulf in the late summer with an average sea surface velocity of 83 cm/sec and a questionable maximum sea surface velocity of 161 cm/sec (calculated from a shallow station). By late winter the average sea surface velocity and the maximum velocity had decreased. The locations of the maximum sea surface velocity and the extremities of the current were farther east of the Yucatan Peninsula in the summer than in the winter. Volume transport into the Gulf was about the same for both cruises.

Both cruises passed along the same line on their southwest transit toward the Yucatan Channel. Stations 45 to 55 for cruise 67-A-6 (Figure 8) and stations 14 to 22 for cruise 68-A-2 (Figure 3) define this path. Section C of cruise 67-A-6 and section B of cruise 68-A-2 were contained between the respective stations. A comparison of sections B and C indicated that the location of the Loop Current had apparently moved to the northwest and had broadened from the summer to the winter. The location of the maximum sea surface current had moved 115 km, but the magnitude had only decreased 3 cm/sec. With the exception of the indicated 161 cm/sec maximum sea surface velocity as the current entered the Gulf on cruise 67-A-6, the value of the maximum sea surface velocity for both cruises was largest at these

two sections. Further, the magnitude of the average velocity had only decreased by 6 cm/sec. The volume transport between the two sections increased from the summer to the winter from 28 to 42.3 Sv. This increase may have been partly caused by the apparent eastward flow across the Campeche Bank during the winter.

The eastern portion of the Loop Current was not observed. No comparison therefore could be made with the current as it approached the Florida Straits.

The apparent detached anti-cyclonic eddy indicated by the summer cruise possibly moved off the Campeche Bank during the winter resulting in the observed anti-cyclonic eddy in the western Gulf for the winter cruise. If so, the intensity of the eddy apparently decreased over this time.

The analyzed charts of the depth of the 22°C isotherm, for both cruises, indicated a cold ridge crossing the Gulf from the shelf off the western coast of Florida to the Campeche Bank. The charts of dynamic topography for the water surface, relative to 1000 meters, (Figures 4 and 9) indicated the presence of this cold ridge by areas of low dynamic topography north of the Loop Current. This cold ridge apparently persisted between the cruises, so the Loop Current did not move any farther north than 25°N latitude.

VI. COMPARISON OF CRUISES 65-A-11, 65-A-13, 66-A-15, AND 67-A-6

Cruise 65-A-11 was conducted from 10-24 August 1965. Hurricane BETSY occurred immediately after this cruise and an opportunity was provided to make observations in areas just surveyed by cruise 65-A-11. This was cruise 65-A-13 of 12-24 September 1965. Cruise 66-A-15 was conducted from 27 October-13 November 1966. These three cruises were analyzed by Hewitt [1970] using Equation (1), Appendix A, to compute volume transport in the layers 0-200m, 0-500m, and 0-1000m, relative to the bottom of the respective layers. The Loop Current and eddy extremities were also determined by Hewitt using the BT method previously discussed in this paper.

A comparison of the cruises was made, since the three cruises were conducted during approximately the same season (late summer to fall) as cruise 67-A-6. A comparison of Hewitt's volume transports in the selected layers relative to the bottom of the layers, to those relative to 1000 meters, was made using the same station pairs. The inferred dynamic heights from the depth of the 22°C isotherm for BT or shallow stations were not changed. Tables XIV, XV, XVI, and XVII indicate the BT and shallow stations by an (I).

Previous analyses in this paper were made of volume transport around the Loop Current. Hewitt also analyzed volume transport around observed eddies, referring to this transport as axial volume transport. Axial volume transport was computed using the station at the apparent center of an eddy together with a station at the outer extremity of the eddy. Tables XIV, XV, and XVI indicate the axial volume transport in the 0-200, 0-500, and 0-1000 meter layers, relative to 1000

meters and to the bottom of the respective layers. The volume transport in the 0-1000 meter layer was, of course, the same when using 1000 meters or the bottom of the layer. However, there were significant differences in volume transports in the 0-200 meter and 0-500 meter layers when the deeper reference level was used.

Cruise 65-A-11 observed one well defined anti-cyclonic eddy centered at 25°15'N, 87°25'W which apparently became detached from the Loop Current. The eddy extended from 23°20'N to 28°N and from 85°W to 89°W. This eddy was crossed five times, providing a good volume transport continuity analysis. The Loop Current was crossed only once.

TABLE XIV

AXIAL GEOSTROPHIC VOLUME TRANSPORT IN SELECTED LAYERS RELATIVE TO 1000 METERS AND TO THE BOTTOM OF THE RESPECTIVE LAYERS (CRUISE 65-A-11)

STATION PAIRS *	LAYERS (m)	VOLUME TRANSPORT RELATIVE TO 1000 m (Sv)	VOLUME TRANSPORT RELATIVE TO BOTTOM OF LAYER (Sv)
22(I)-26 (E)	0-1000	34.9	34.9
18-26 (E)	0-200 0-500 0-1000	21.0 35.5 41.9	6.0 20.4 41.9
26-27 (E)	0-200 0-500 0-1000	20.0 34.5 41.4	6.0 18.5 41.4
24(I)-26 (E)	0-1000	43.8	43.8
25-26 (E)	0-200 0-500 0-1000	18.5 30.5 36.3	6.3 17.7 36.3
25(I)-25(J) (Y)	0-1000	20.3	20.3

*Note: I or J-station used an inferred dynamic height
E-Eddy
Y-Yucatan current

One large well defined anti-cyclonic eddy was observed by cruise 65-A-13. This eddy consisted of two smaller eddies referred to as the "upper eddy" and the "lower eddy". The "lower eddy" was centered at 24°19'N, 87°25'W. The "upper eddy" was centered at 26°20'N, 86°55'W. The combination of eddies extended from 23°10'N to 26°30'N and from 85°10'W to 88°30'W. A small anti-cyclonic eddy was observed to the north of the "upper eddy". The Loop Current was not observed on this cruise.

TABLE XV

AXIAL GEOSTROPHIC VOLUME TRANSPORT IN SELECTED LAYERS RELATIVE TO 1000 METERS AND TO THE BOTTOM OF THE RESPECTIVE LAYERS (Cruise 65-A-13)

STATION PAIRS *	LAYERS (m)	VOLUME TRANSPORT RELATIVE TO 1000 m (Sv)	VOLUME TRANSPORT RELATIVE TO BOTTOM OF LAYER (Sv)
34-16 (U)	0-200	11.8	5.3
	0-500	17.2	12.2
	0-1000	19.2	19.2
13-16 (U)	0-200	10.8	4.1
	0-500	16.8	11.2
	0-1000	19.0	19.0
16-28(I) (U)	0-1000	19.0	19.0
16-19 (U)	0-200	10.5	4.3
	0-500	16.0	10.6
	0-1000	18.2	18.2
22-23 (L)	0-200	8.4	3.2
	0-500	13.3	8.4
	0-1000	15.5	15.5
22-20 (L)	0-200	9.1	4.0
	0-500	13.9	8.6
	0-1000	16.5	16.5
22-21(I) (L)	0-1000	13.4	13.4
12-13 (N)	0-200	3.1	1.2
	0-500	5.3	2.9
	0-1000	6.4	6.4
10(I)-12 (N)	0-1000	6.7	6.7

*Note: I-station used an inferred dynamic height
U-Upper eddy
L-Lower eddy
N-Northern eddy

The Loop Current was observed nine times on cruise 66-A-15. It entered the Gulf at the Yucatan Channel and flowed north to the northern tip of the Campeche Bank and then turned to the west into the central Gulf. The farthest extension to the west was 91°30'W. The current then turned northeast until it turned at 28°30'W, 88°30'W toward the Florida Straits. The current consisted of a northern and southern eddy. Hewitt [1970] analyzed the axial volume transport around the eddies (Table XVI) and the Loop Current volume transport (Table XVII). The stations which are underlined in these tables represent a second station with the same number as a previous station on this same cruise.

The variation in volume transport in the 0-200 meter and 0-500 meter layers, using the layer bottoms on one hand and the 1000 meter surface of the other, was caused by variation in the geostrophic velocities of the 200 and 500 meter water surfaces. Plots of water velocity, relative to 1000 meters, versus depth for cruises 65-A-11, 65-A-13, and 66-A-15 indicated that the majority of the velocities (relative to 1000 meters) of the 200 meter surface were at least 40 percent of the velocity (relative to 1000 meters) of the sea surface. The 500 meter water surface had an average velocity (relative to 1000 meters) of 10 cm/sec for most cruises. Therefore, any assumption that these water surfaces were levels of no motion would produce differences in the volume transport indicated in the preceeding tables.

There was a small range of volume transport differences for cruise 65-A-11 of 12-15 Sv (Table XIV) at each layer for all station pairs. An analysis of the velocities of the 200 and 500 meter water surfaces and the difference in dynamic heights of the sea surface, both relative to 1000 meters, at each station pair indicated the following; a

TABLE XVI

AXIAL GEOSTROPHIC VOLUME TRANSPORT IN SELECTED LAYERS RELATIVE TO 1000 METERS AND TO THE BOTTOM OF THE RESPECTIVE LAYERS (Cruise 66-A-15)			
STATION PAIRS *	LAYERS (m)	VOLUME TRANSPORT RELATIVE TO 1000 m (Sv)	VOLUME TRANSPORT RELATIVE TO BOTTOM OF LAYER (Sv)
12-T(I) (S)	0-1000	30.3	30.3
12-5(I) (S)	0-1000	49.2	49.2
12-6(I) (S)	0-1000	48.6	48.6
12-16(I)(S)	0-1000	46.1	46.1
12-21	0-200	19.5	-
(S)	0-500	30.1	-
	0-1000	35.0	-
12-22	0-200	4.8	0.1
(S)	0-500	8.8	4.0
	0-1000	11.1	11.1
12-24	0-200	23.3	-
(S)	0-500	38.8	-
	0-1000	45.9	45.9
12-25(I)(S)	0-1000	42.9	42.9
12-26(I)(S)	0-1000	39.9	39.9
12-2	0-200	16.0	-
(S)	0-500	26.6	-
	0-1000	31.5	36.4
12-3	0-200	4.8	-
(S)	0-500	7.9	-
	0-1000	9.6	9.6
7-22	0-200	4.4 West	0.4 East
(N)	0-500	8.2 West	6.6 West
	0-1000	9.1 West	9.1 West
7-21	0-200	18.5	7.0
(N)	0-500	28.7	21.5
	0-1000	31.9	31.9
7-19	0-200	21.2	7.6
(N)	0-500	33.8	23.9
	0-1000	37.8	37.8
7-4	0-200	18.7	6.3
(N)	0-500	30.2	20.9
	0-1000	34.3	34.3
7-11	0-200	20.1	6.9
(N)	0-500	32.5	22.2
	0-1000	36.7	36.7
7-15	0-200	21.2	7.0
(N)	0-500	34.9	23.2
	0-1000	39.8	39.8
7-24	0-200	22.2	7.0
(N)	0-500	37.0	24.0
	0-1000	42.5	42.5

*Note: T-Inferred station 19 km west of the western tip of Cuba
I-Station used inferred dynamic height
S-South eddy
N-North eddy

TABLE XVII

LOOP CURRENT GEOSTROPHIC VOLUME TRANSPORT IN SELECTED LAYERS RELATIVE TO 1000 METERS AND TO THE BOTTOM OF THE RESPECTIVE LAYERS (Cruise 66-A-15)			
STATION PAIRS *	LAYERS (m)	VOLUME TRANSPORT RELATIVE TO 1000 m (Sv)	VOLUME TRANSPORT RELATIVE TO BOTTOM OF LAYER (Sv)
6(I)-7(I)	0-1000	16.6	16.6
7(I)-10(I)	0-1000	23.0	23.0
20(I)-21	0-1000	11.6	11.6
21-22	0-200 0-500 0-1000	14.5 20.8 23.1	6.6 15.1 23.1
17-19	0-200 0-500 0-1000	18.1 28.1 32.0	7.0 18.8 32.0
4-6	0-200 0-500 0-1000	14.2 22.3 25.7	5.8 14.4 25.7
6-7	0-200 0-500 0-1000	4.5 8.1 8.7	.6 6.6 8.7
7-9	0-200 0-500 0-1000	6.1 10.7 11.9	1.1 8.1 11.9
9-11	0-200 0-500 0-100	13.9 21.5 24.6	5.7 14.0 24.6
15-17	0-200 0-500 0-1000	18.2 29.4 34.2	6.4 18.3 34.2
22-24	0-200 0-500 0-1000	18.2 29.4 34.1	6.7 17.9 34.1
26(I)-26(J)	0-1000	32.4	32.4
1(I)-3	0-1000	27.0	27.0

*Note: I or J-station used an inferred dynamic height

range of velocities at 200 meters of 24-26 cm/sec, a range of velocities at 500 meters of 10-12 cm/sec, and a range of dynamic height differences of 0.7-0.8 m^2/sec^2.

The relatively constant volume transport difference for the 0-200 meter and 0-500 meter layers for each individual station pair was explained by the fact that the water in the 0-200 meter layer was flowing through a vertical cross-section of 200 meters multiplied by the distance between the station pair at an added velocity of 24 cm/sec, while the water in the 0-500 meter layer was flowing through an area 2.5 times as large as that between 0-200 meters but with an added velocity which was only 0.4 (1/2.5) times that of the water between 0-200 meters. As explained previously in the section on procedures, station pairs with the same difference in dynamic heights of the sea surface, relative to 1000 meters, will have the same total transport in the 0-1000 meter layer, but the distribution of the volume transport by layers may differ for individual station pairs. However, since the velocities of the 200 and 500 meter water surfaces are relatively constant for all station pairs of cruise 65-A-11, the volume transport distribution in the 0-200 meter and 0-500 meter layers must have been such as to produce a relatively constant volume transport difference for the 0-200 meter layer at all station pairs and the 0-500 meter layer at all station pairs.

The differences in volume transport (Table XV) in the 0-200 meter and 0-500 meter layers for cruise 65-A-13 were approximately 5-6 Sv except for stations 12-13, which had a difference of approximately 2 Sv. The average velocities (relative to 1000 meters) of the 200 and 500 meter water surfaces were 25 cm/sec and 11 cm/sec respectively,

for all station pairs except station pair 12-13. Station pair 12-13 had a velocity, relative to 1000 meters, of 16 cm/sec at 200 meters and 8 cm/sec at 500 meters. The range of dynamic height differences of the sea surface, relative to 1000 meters, for all station pairs except station pair 12-13, was 0.3-0.5 m^2/sec^2. This constant volume transport difference was explained by the same reasons as given for cruise 65-A-11. The smaller difference was due to the smaller differences in dynamic heights of the sea surface, relative to 1000 meters.

Different velocities of the 200 and 500 meter water surfaces were found for cruise 66-A-15, accounting for significant volume transport differences in the 0-200 meter and 0-500 meter layers, but no relatively constant difference was found as for cruises 65-A-11 and 65-A-13. For station pair 7-22 (Table XVI), Hewitt indicated an eastward transport in the 0-200 meter layer. This was apparently the only instance a reversal in direction of volume transport in one layer, as compared to other layers, occurred in Hewitt's computations. However, calculations of volume transport, relative to 1000 meters, indicated westward transport throughout the entire column of water from the sea surface to 1000 meters. This indicates that it is possible to have a direction reversal in a layer when a different reference level is chosen.

These tables also indicate that, as for cruise 67-A-6, the largest portion of volume transport, relative to 1000 meters, for all cruises occurred in the layer 0-200 meters as compared to the layers of 200-500 meters and of 500-1000 meters. For the majority of station pairs, over half of the total transport in the layer of 0-1000 meters occurred in the upper 200 meters of water. When the bottom of the

layer was used as the reference level, the volume transport in the 0-200 meter layer was much less than the 200-500 meter and 500-1000 meter layers.

The difference of 7.5 Sv between station pairs 24(I)-26 and 25-26 for cruise 65-A-11 (Table XIV) was apparently caused by a loss of volume transport through the Florida Straits. To provide volume transport continuity, the 7.5 Sv were added to the 20.3 Sv between station pair 25(I)-25(J) providing an inferred volume transport of 27.8 Sv into the Gulf. This value corresponds closely to the 27.5 Sv of input into the Gulf for cruise 67-A-6. Cruise 66-A-15 indicated a volume transport of only 19.6 Sv through the Yucatan Channel.

The location of the Loop Current in the Yucatan Channel for cruise 65-A-11 was considerably farther to the east as compared to cruises 66-A-15 and 67-A-6, and flowed along the northern coast of Cuba. The Loop Current for cruises 66-A-15 and 67-A-6 was close to the Yucatan Peninsula and flowed generally to the north into the eastern Gulf. The Loop Current for cruise 66-A-15 intruded into the central Gulf and as far north as the 1000 meter depth contour south of the Mississippi Delta before turning toward the Florida Straits. Cruise 67-A-6 observed the Loop Current turning toward the Florida Straits at 25^{o}N latitude, never intruding into the central Gulf.

All the cruises except 66-A-15 observed at least one major eddy which apparently had become detached from the Loop Current. Cruise 66-A-15 observed a northern and a southern loop within the Loop Current which apparently had closed flows around their centers. The eddies for cruises 65-A-11 and 65-A-13 were well defined and located in the eastern Gulf. The eddy observed by cruise 67-A-6 was in the western Gulf, but only one section of it was observed.

VII. SUMMARY OF LOOP CURRENT AND EDDY VELOCITIES AND VOLUME TRANSPORTS FOR NINE SUMMER AND WINTER CRUISES IN THE GULF OF MEXICO FROM 1965-1968

Calculated sea surface velocities and volume transports for the Loop Current and observed eddies of selected ALAMINOS cruises, 65-A-11, 65-A-13, 66-A-8, 66-A-11, 66-A-15, 67-A-1, 67-A-6, 68-A-2, and 68-A-8 are summarized in Table XVIII and XIX. The values of volume transports are for the entire water column from the sea surface to the chosen reference level. Cruise 66-A-8 chose 1350 meters as the reference level, while the remaining cruises chose 1000 meters. Also, cruise 66-A-8 did not observe the Loop Current in the Yucatan Channel, so the values indicated in Table XVIII are for a cross-section 360 km north of the channel.

Cruise 67-A-1 only took hydrographic measurements down to 300 meters, so the tables only indicate the volume transport in the upper 300 meters of water. The upper 200 to 300 meters of water usually accounted for approximately 50 per cent of the volume transport in previous analyses, so doubling the indicated values should be indicative of the magnitude of the volume transport for the entire column of water from the sea surface to 1000 meters.

Tables XVIII and XIX present an indication of the variations in the calculated values for seasons and in time.

TABLE XVIII

SUMMARY OF LOOP CURRENT SEA SURFACE VELOCITIES AND VOLUME TRANSPORTS, RELATIVE TO THE CHOSEN REFERENCE LEVEL, AT THE YUCATAN CHANNEL FOR SELECTED CRUISES				
CRUISE	REFERENCE LEVEL (m)	AVERAGE VELOCITY (cm/sec)	MAXIMUM VELOCITY (cm/sec)	VOLUME TRANSPORT (Sv)
65-A-11 (August)	1000	-	121	27.8
65-A-13 (Sept.)	1000	No Loop Current observed		
66-A-8 (June)	1000	-	100	36.0
66-A-11 (August)	1350	-	102	45.0
66-A-15 (Oct-Nov)	1000	-	125	46.1
67-A-1 (April)	300	No Loop Current observed		
67-A-6 (August)	1000	83	161*	27.5
68-A-2 (Feb-Mar)	1000	80	91	26.6
68-A-8 (August)	1000	70	107	23.3

*Note: This velocity was the result of a shallow station analysis

TABLE XIX

SUMMARY OF OBSERVED ANTI-CYCLONIC EDDY SEA SURFACE VELOCITIES AND VOLUME TRANSPORTS, RELATIVE TO THE CHOSEN REFERENCE LEVEL, FOR SELECTED CRUISES				
CRUISE	REFERENCE LEVEL (m)	LOCATION OF EDDY CENTER	RANGE OF MAXIMUM VELOCITIES AROUND THE EDDY (cm/sec)	AVERAGE VOLUME TRANSPORT (Sv)
65-A-11 (August)	1000	25°15'N 87°25'W	65-129	39.6
65-A-13 (Sept.)	1000	26°20'N 86°55'W	49-120	19.0
	1000	24°19'N 87°25'W	55-73	15.1
	1000	28°20'N 87°13'W	33-35	6.6
66-A-8 (June)	1000	25°30'N 86°30'W	100-150	45.0
66-A-11 (August)	1350	26°00'N 88°00'W	101-116	42.7
	1350	23°50'N 85°45'W	106*	41.2
66-A-15 (Oct-Nov)	1000	26°10'N 88°55'W	80-183	37.5
	1000	23°45'N 85°50'W	91-130	41.0
67-A-1 (April)	300	26°35'N 91°05'W	11-33	1.5
67-A-6 (August)	1000	24°24'N 88°55'W	76*	21.3
68-A-2 (Feb-Mar)	1000	24°30'N 93°42'W	21*	7.1
68-A-8 (August)	1000	25°30'N 87°00'W	55-130	35.0

*Note: Only one section of the eddy was observed

VIII. CONCLUSIONS

The planning of a cruise to observe and study the Loop Current is a formidable task. The location of the current varies with time, and no definite relation between the current's location and time has been proposed. The current does enter the Gulf through the Yucatan Channel and exits the Gulf through the Florida Straits, so these two areas could be used to start a search for the current. However, even in these two areas, the current's location varies greatly with time. There does seem to be a correlation between the current's location in the Yucatan Channel in the fall and winter seasons. The current seems to be closer to the Yucatan Peninsula in the winter than in the fall.

The method of determining the current's extremities from the slope of the 22°C isotherm or the 18°C isotherm seems to lend itself as a plausible method to ensure that hydrographic stations are made at the proper places to observe the current. Use of X-BT's to obtain temperature versus depth information is a rapid means of obtaining a BT cross-section of an area. With this information the current can be located and hydrographic stations made at the proper places.

The shallow water station (depth of the water is less than the depth of the chosen reference level) is the most subjective part of the analysis of the current's volume transport and velocity. When a shallow station is required to be made, it is recommended that current meters be used to obtain the velocity versus depth profile. Although use of these meters would require more time on station, a much better analysis could be made. This problem is important because the current in the Yucatan Channel and the Florida Straits normally is flowing

over a shallow bottom. Also, the Campeche Bank and the Florida Shelf are areas which should be observed so that the circulation pattern in the Gulf can be better understood. To do this, shallow water stations must be utilized.

The correlation of the depth of the 22°C isotherm with dynamic height of the sea surface, relative to the chosen reference level, seems to be a good method for determining the dynamic height for a BT or shallow water station. A correlation curve should be made for each individual cruise when possible. However, for cruises where the dynamic topography was not determined, this method, using a correlation curve from another cruise, seemed to be successful.

If the observed data are used to calculate the dynamic height and the transport function (Q) assuming the sea surface to be a level of no motion, Equation (1) of Appendix A may be used to calculate the volume transport between a station pair relative to the bottom of the layer or to a true level of no motion which may be determined after the cruise is completed. However, the meaning of the terms in Equation (1) change when the volume transport is not calculated relative to the bottom of the layer. Also, when the volume transport is calculated relative to the bottom of the layer, the layer must include the sea surface as its top boundary. Choosing a reference level and calculating volume transport in increments from that level to the sea surface provided the best analysis of the volume transport between station pairs.

APPENDIX A

EQUATIONS UTILIZED TO COMPUTE GEOSTROPHIC VOLUME TRANSPORT AND VELOCITY

Equations (1)-(3) are given by McLellan [1965; pages 70-71]. Equation (4) is given by Fomin [1964; page 151]. The value of 10 was used for C.

(1) $$T(M,N)_j = -\frac{C}{f} \cdot \left[(Q_{Nj} - Q_{Mj}) - (\Delta D_{Nj} - \Delta D_{Mj}) \cdot Z_r \right]$$

T = transport between stations M and N relative to the j^{th} level

f = Coriolis parameter

$$Q = \sum_{i=1}^{j} \frac{(\Delta D_i + \Delta D_{i-1})}{2} \cdot \Delta Z_i = \text{transport function}$$

ΔZ_i = difference in depths of the (i) and (i-1) surfaces

ΔD = dynamic height anomaly

Z_r = chosen reference depth

(2) $$V = \frac{C \cdot (\Delta D_N - \Delta D_M)}{\Delta X \cdot f}$$

ΔX = distance between stations

(3) $$\Delta T_i = \frac{\Delta X \cdot \Delta Z \cdot (V_i + V_{i-1})}{2} \qquad i = 1, 2, \cdots$$

ΔT = increment of volume transport

(4) $$\Delta = 1/2 \cdot h \cdot (\alpha_{Deep} - \alpha_{Shallow})$$

α = specific volume

h = difference in depths of stations expressed in pressure units

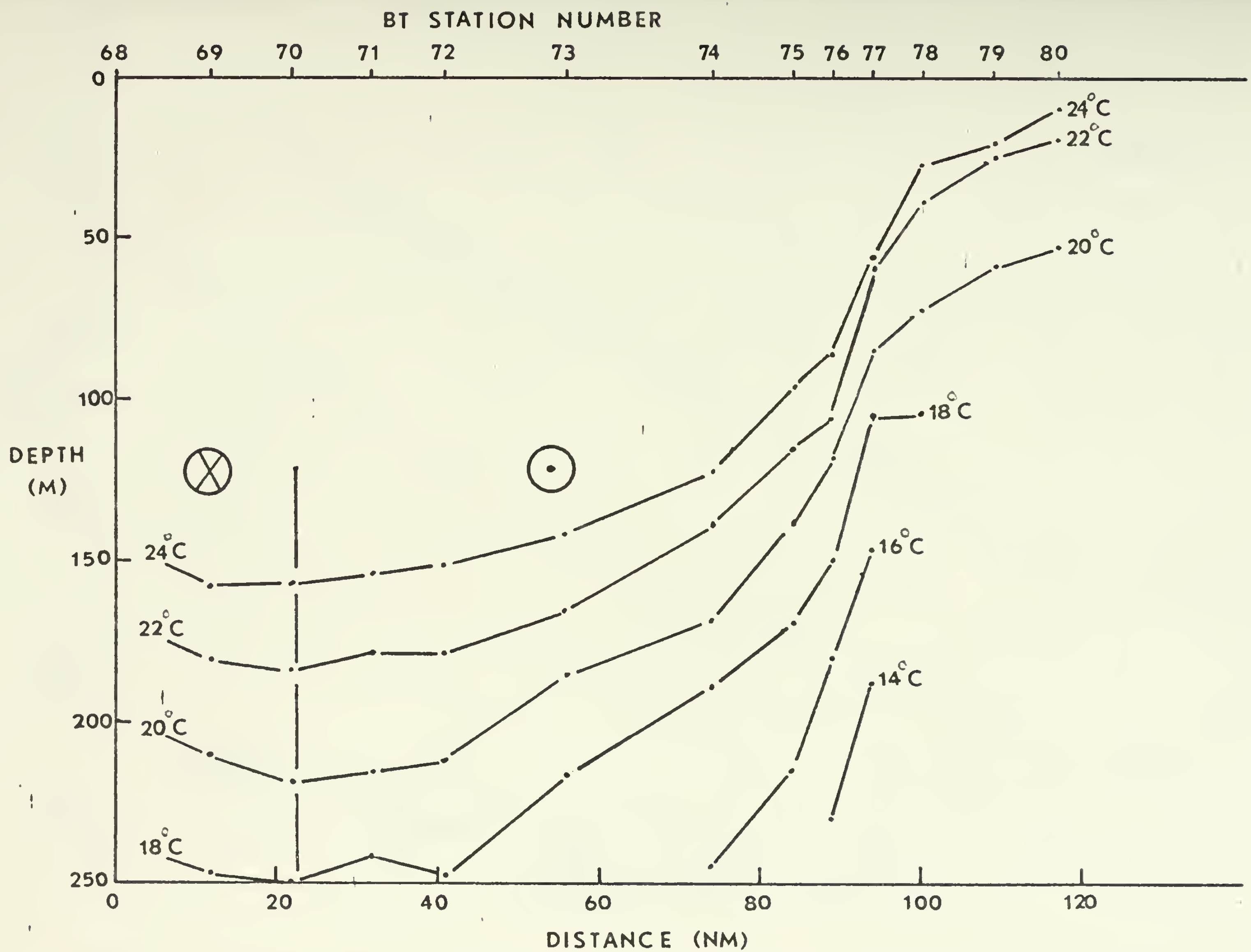


FIGURE 1. Temperature Cross-section of Loop Current

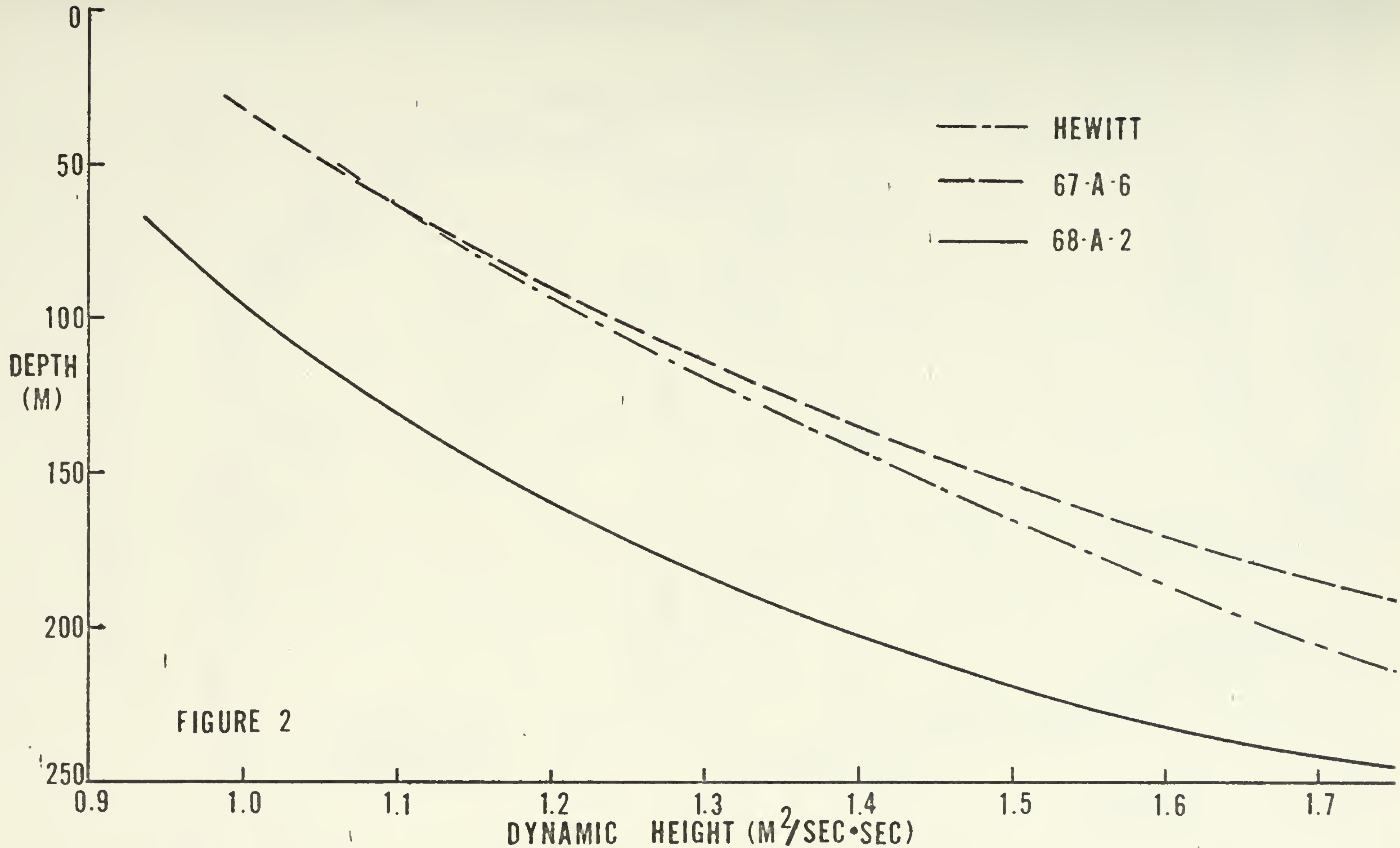
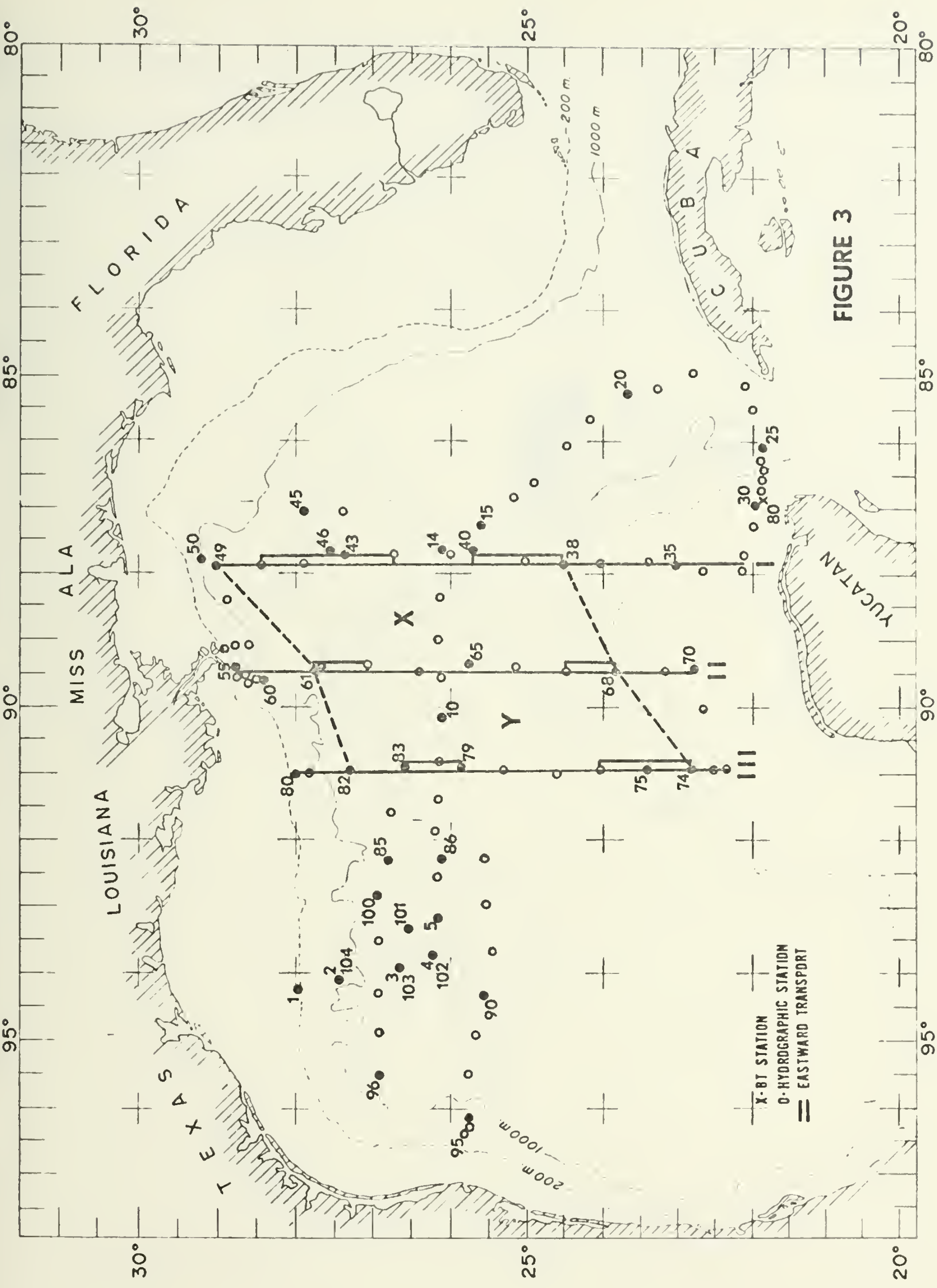
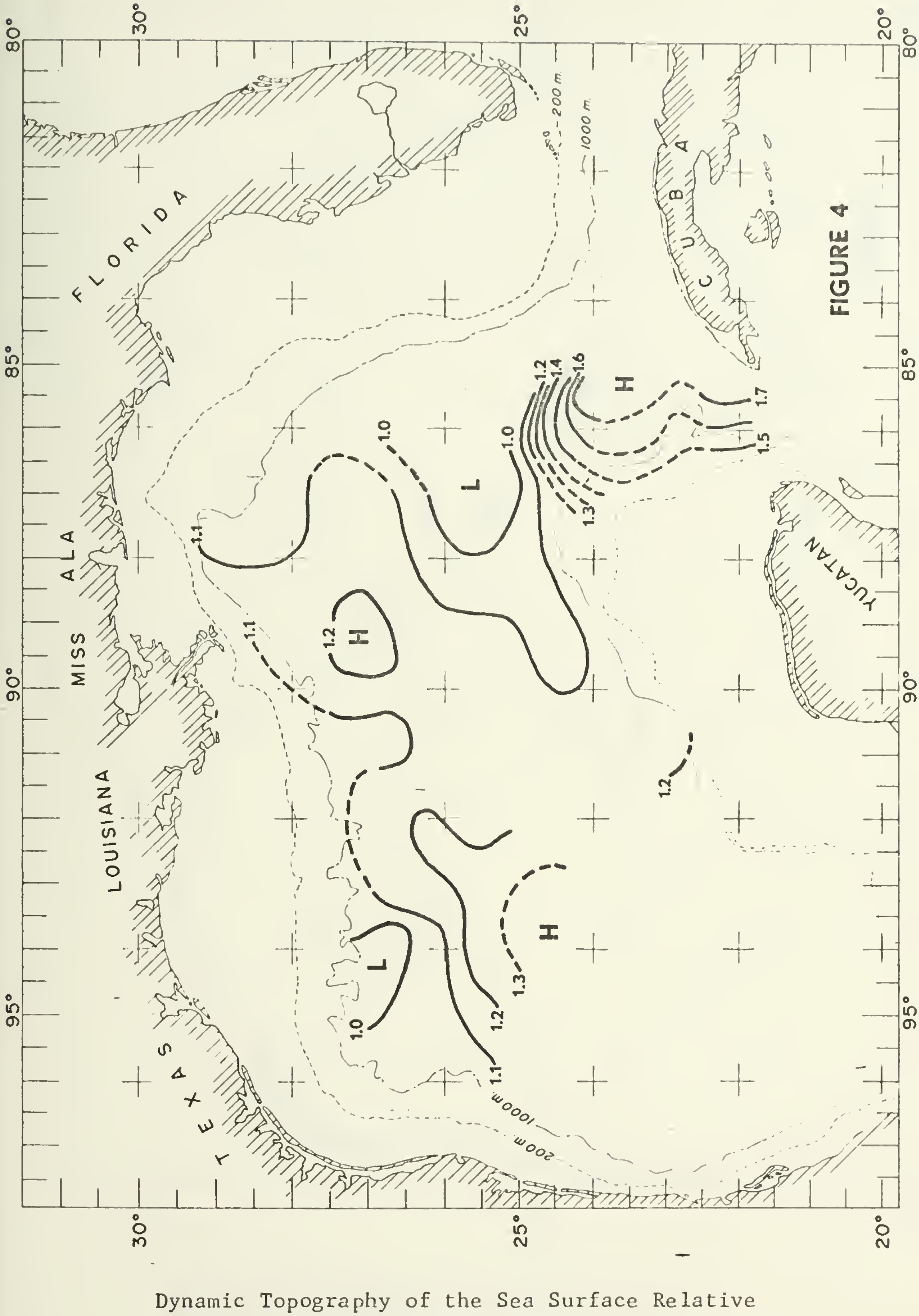


FIGURE 2. Depth of 22°C Isotherm versus Dynamic Height Anomaly of the Sea Surface Relative to 1000 meters.



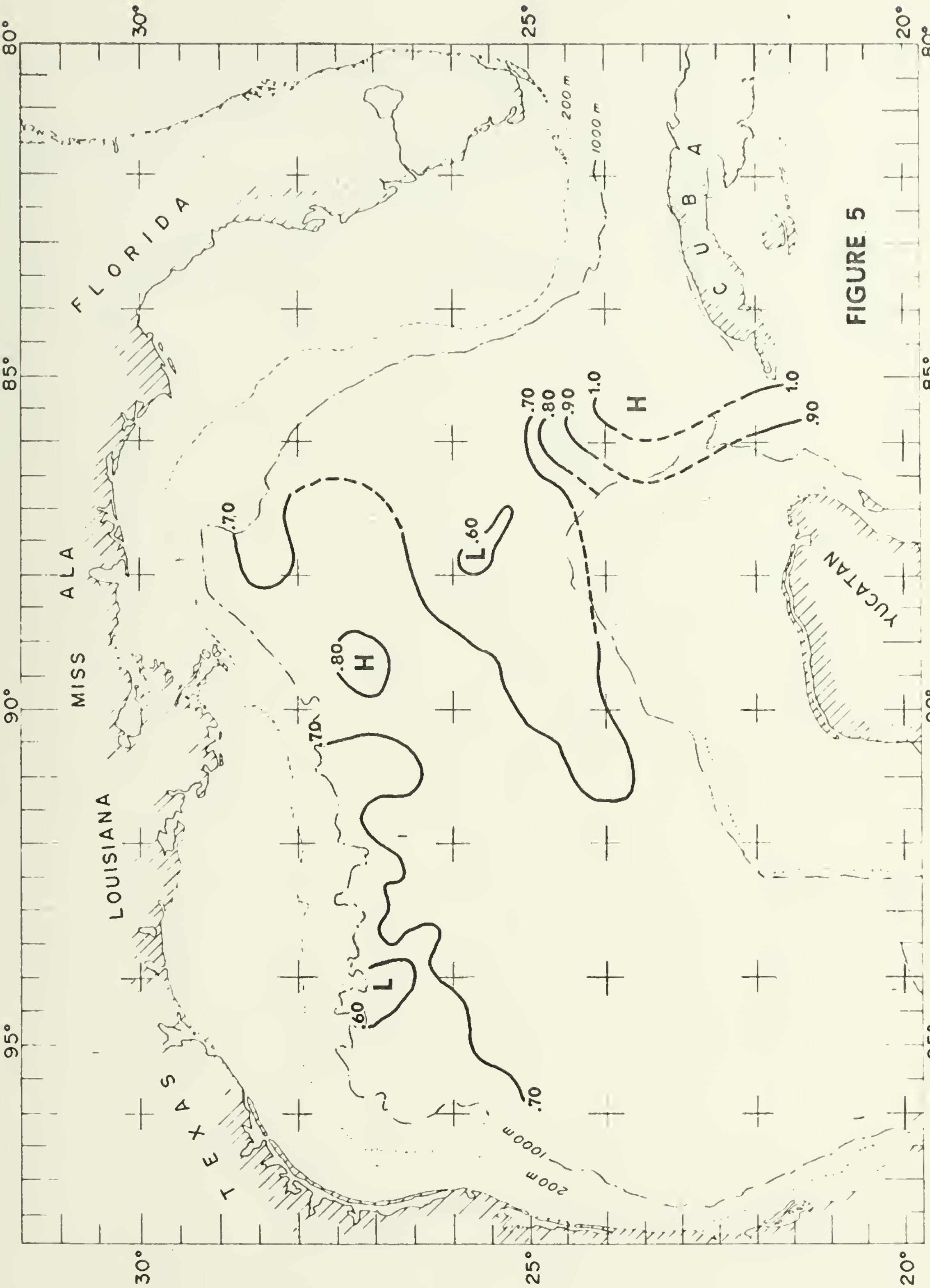
Station Locations, Cruise 68-A-2

Figure 3



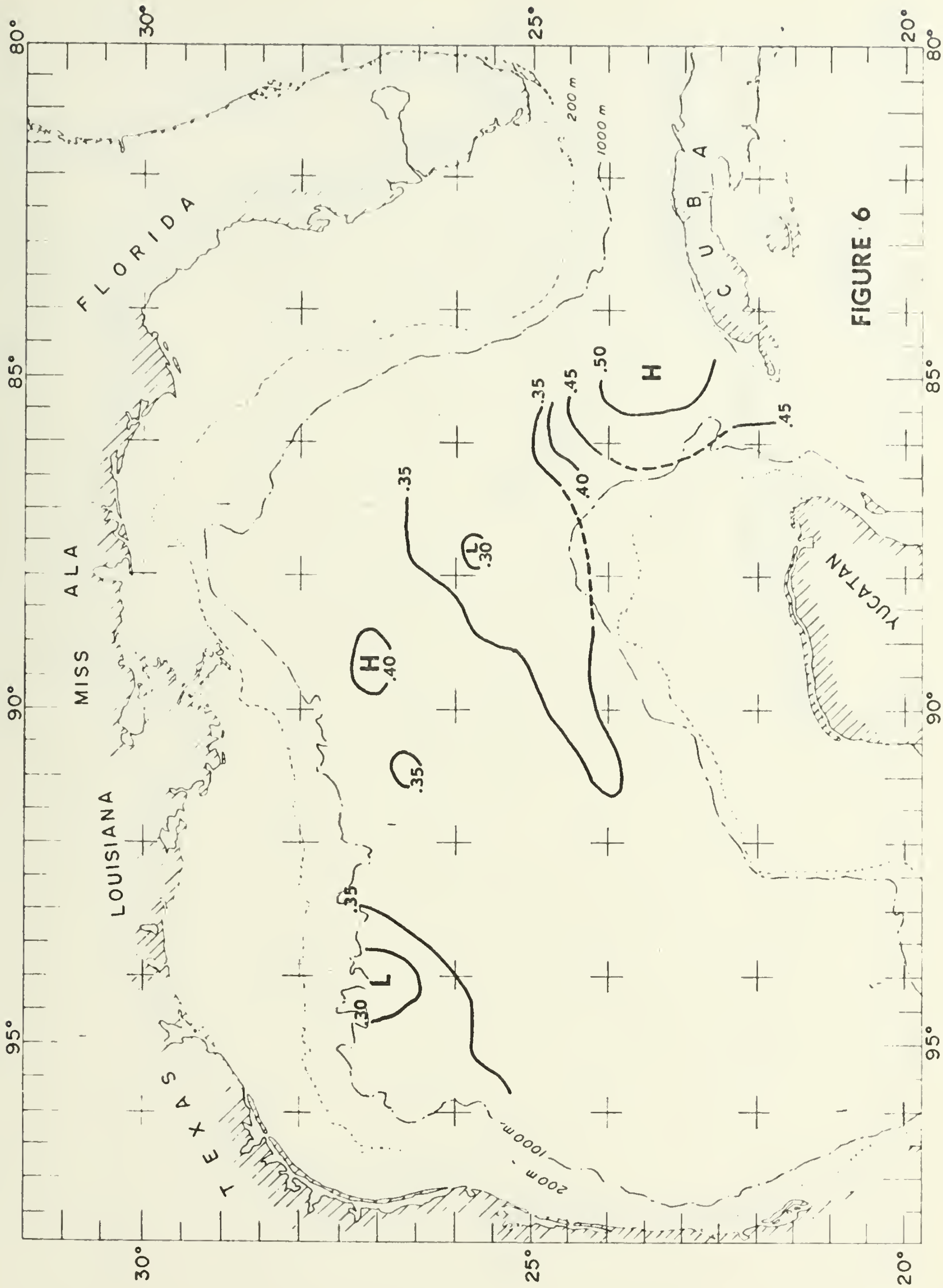
Dynamic Topography of the Sea Surface Relative to 1000 Meters (Cruise 68-A-2)

Figure 4



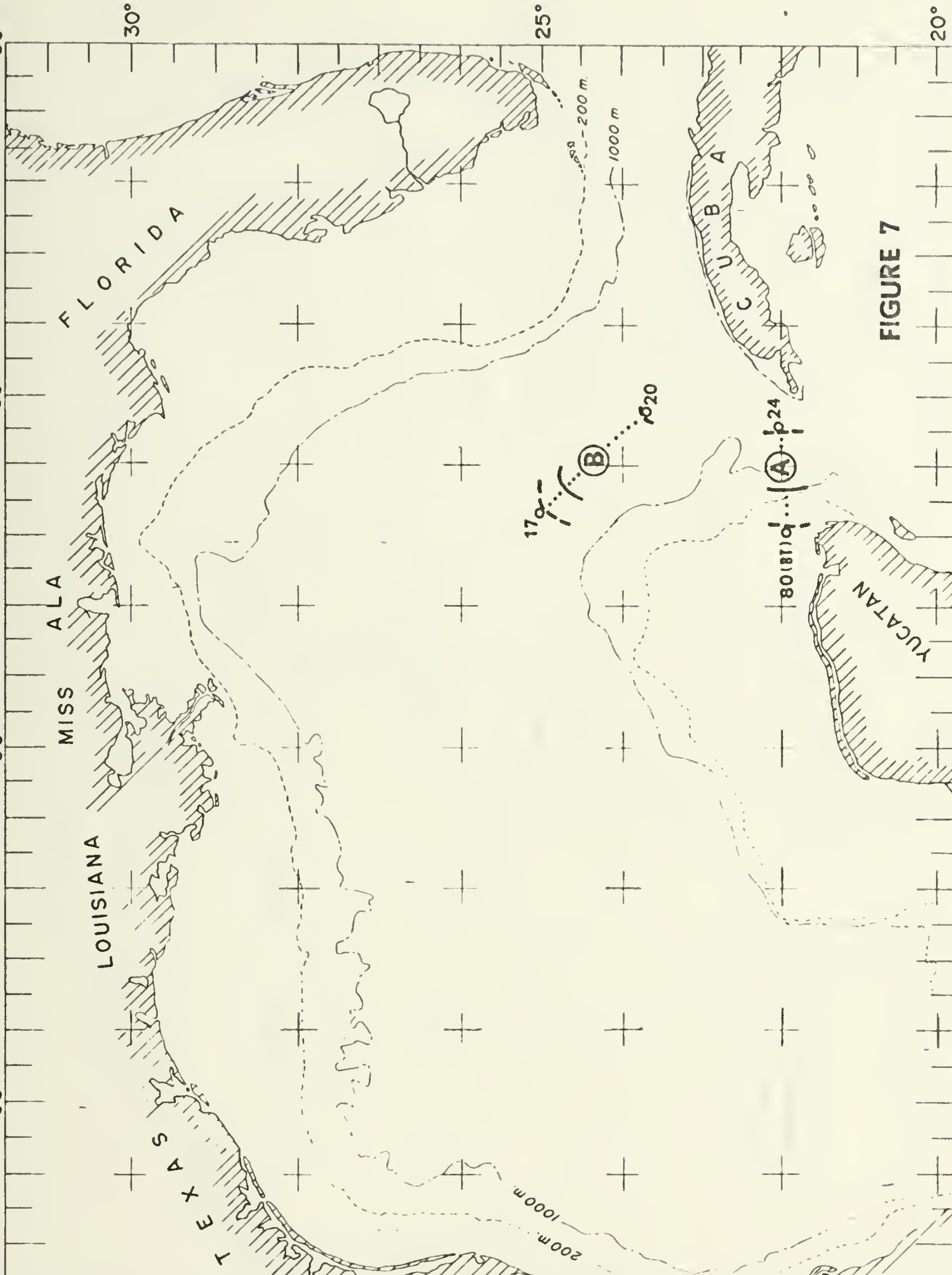
Dynamic Topography of the 200 Meter Surface
Relative to 1000 Meters (Cruise 68-A-2)

Figure 5



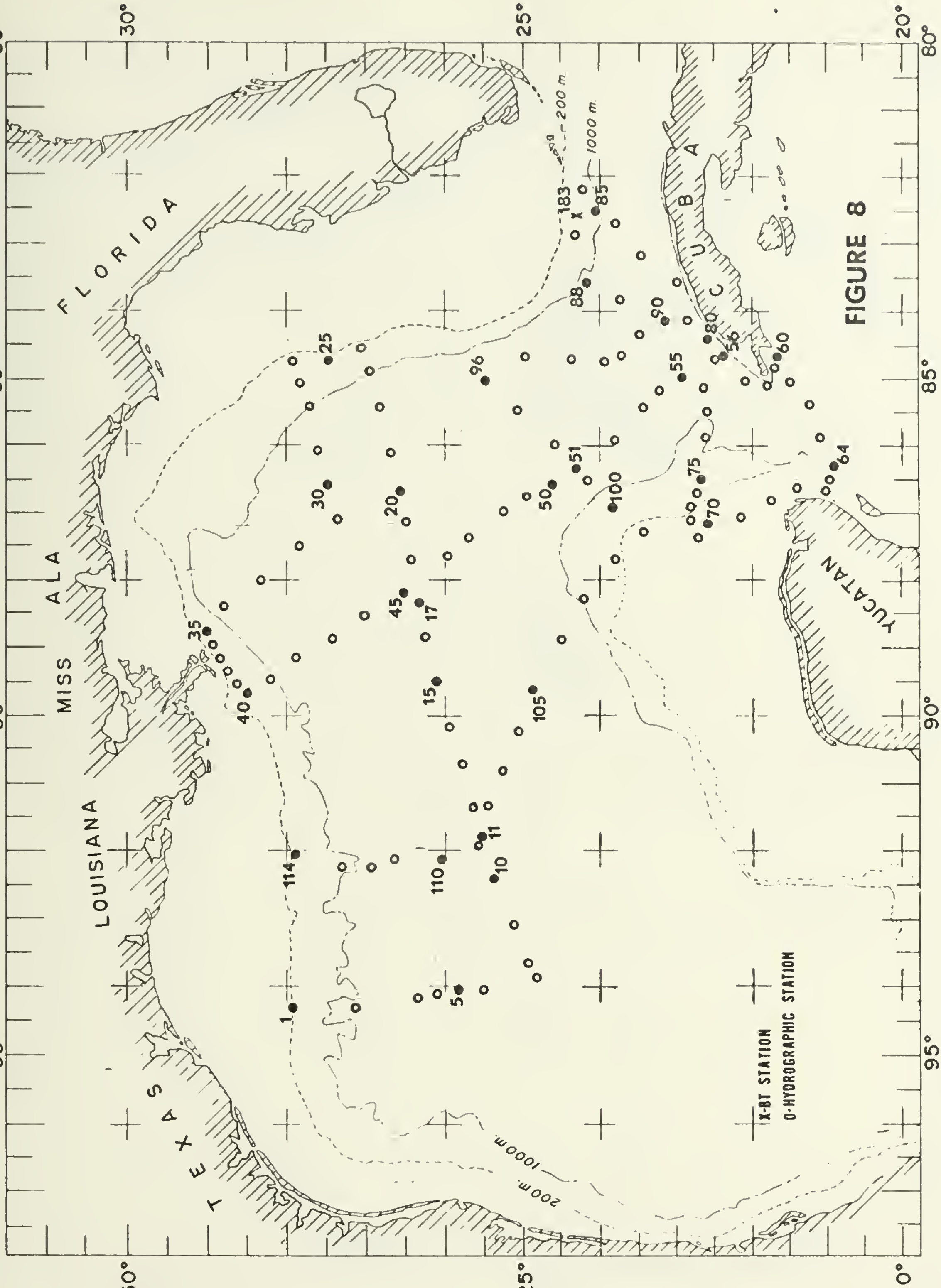
Dynamic Topography of the 500 Meter Surface
Relative to 1000 Meters (Cruise 68-A-2)

Figure 6



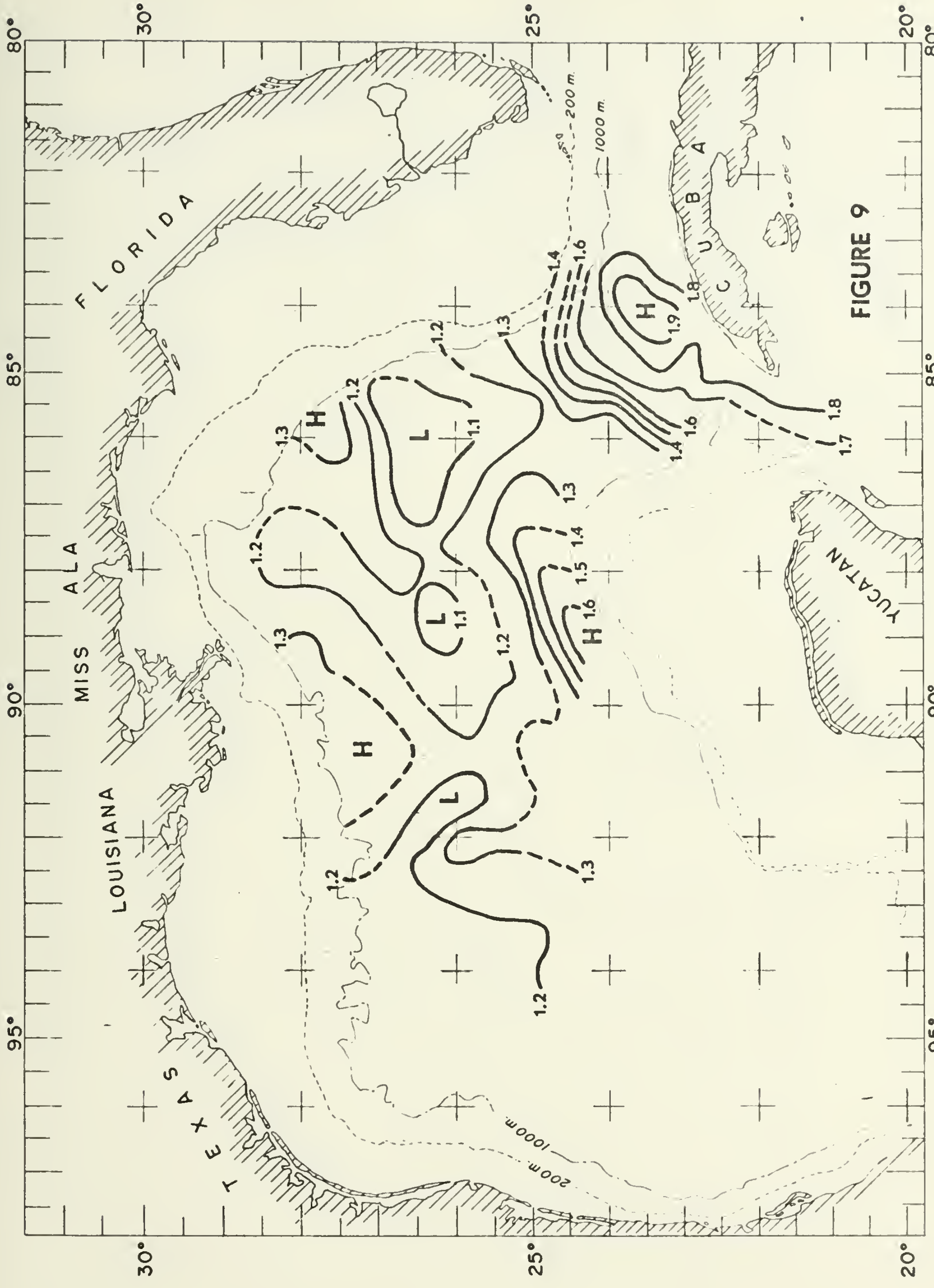
Location of Loop Current (Cruise 68-A-2)

Figure 7



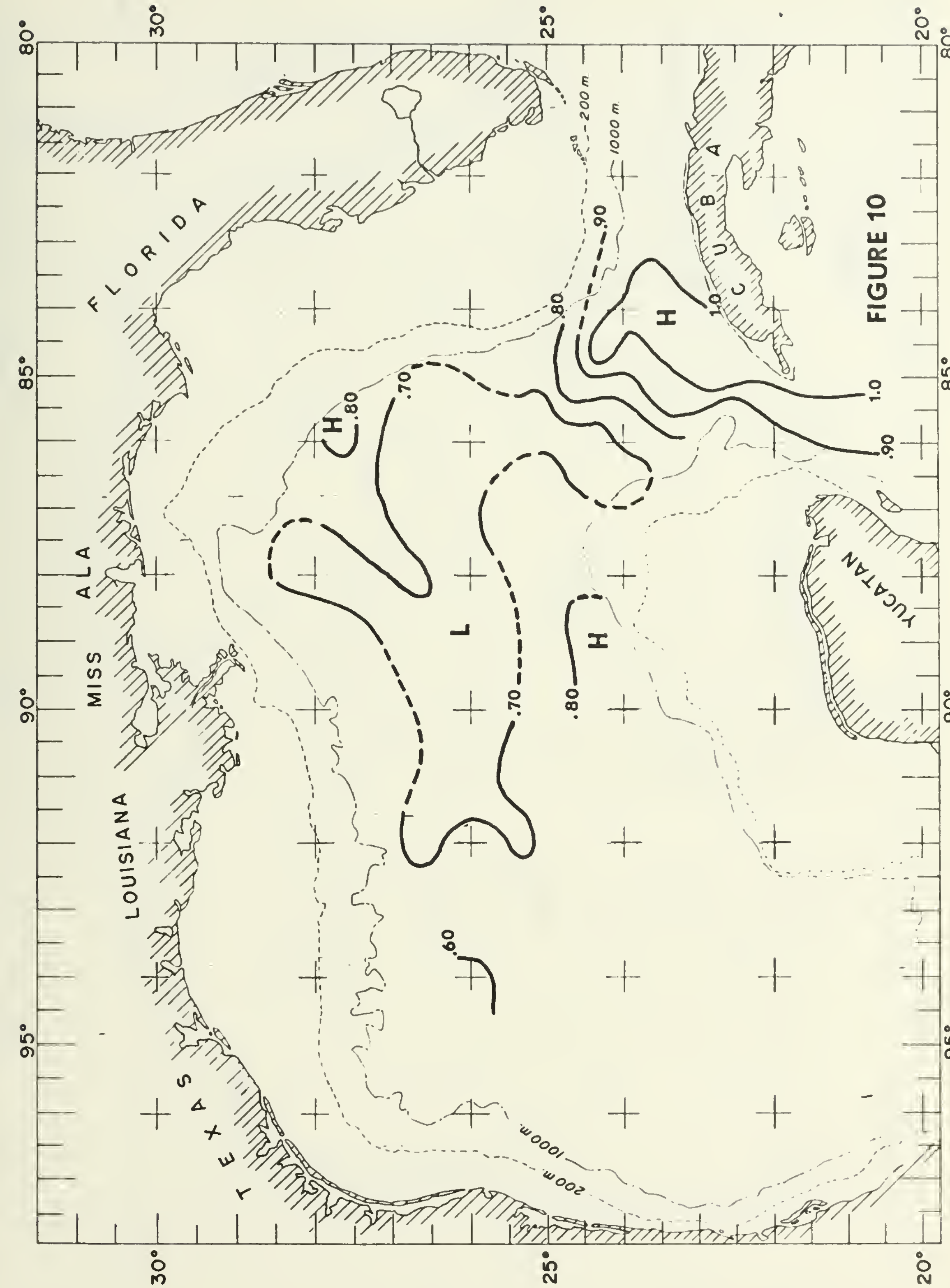
Station Locations, Cruise 67-A-6

Figure 8



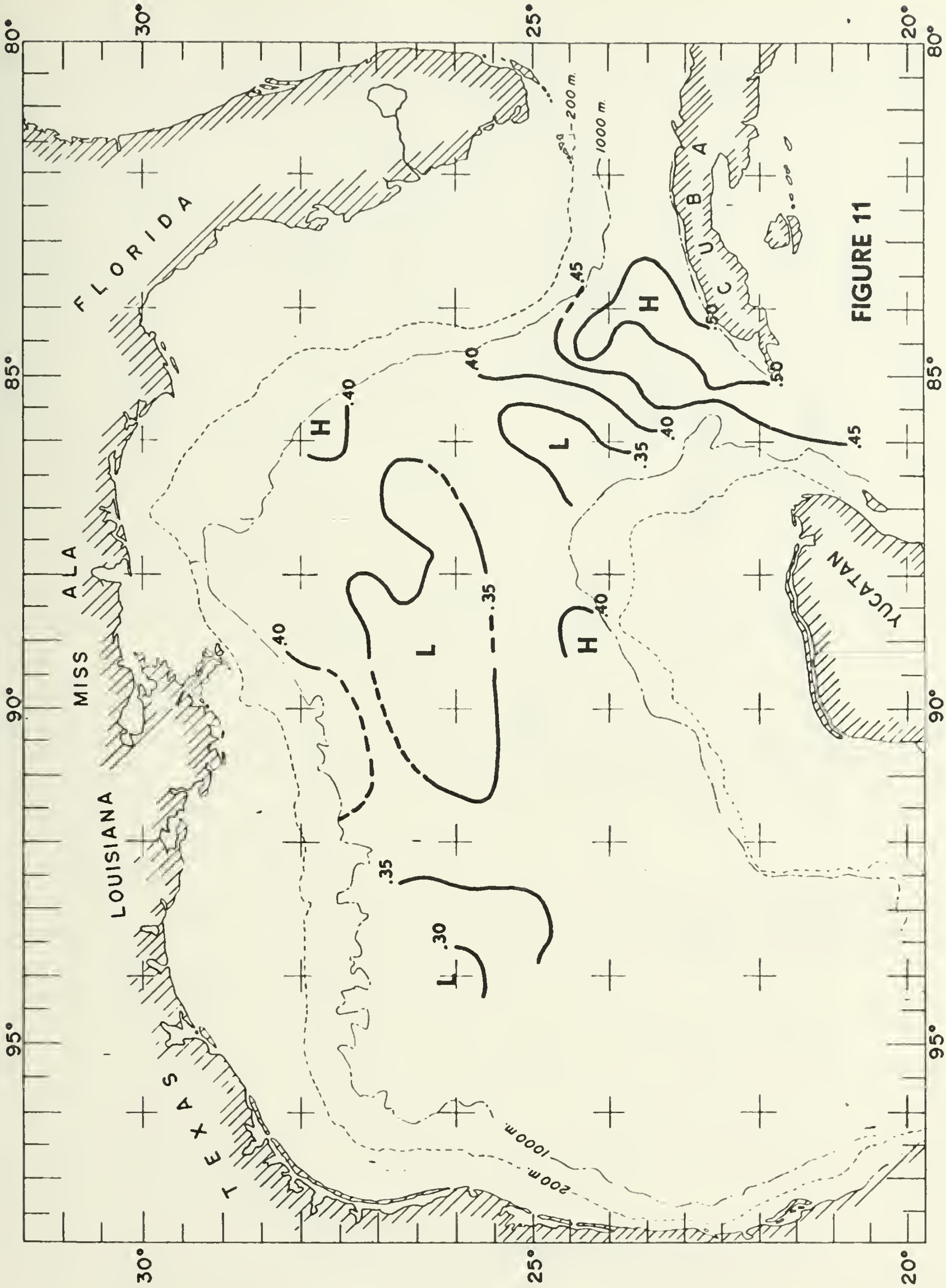
Dynamic Topography of the Sea Surface Relative
to 1000 Meters (Cruise 67-A-6)

Figure 9



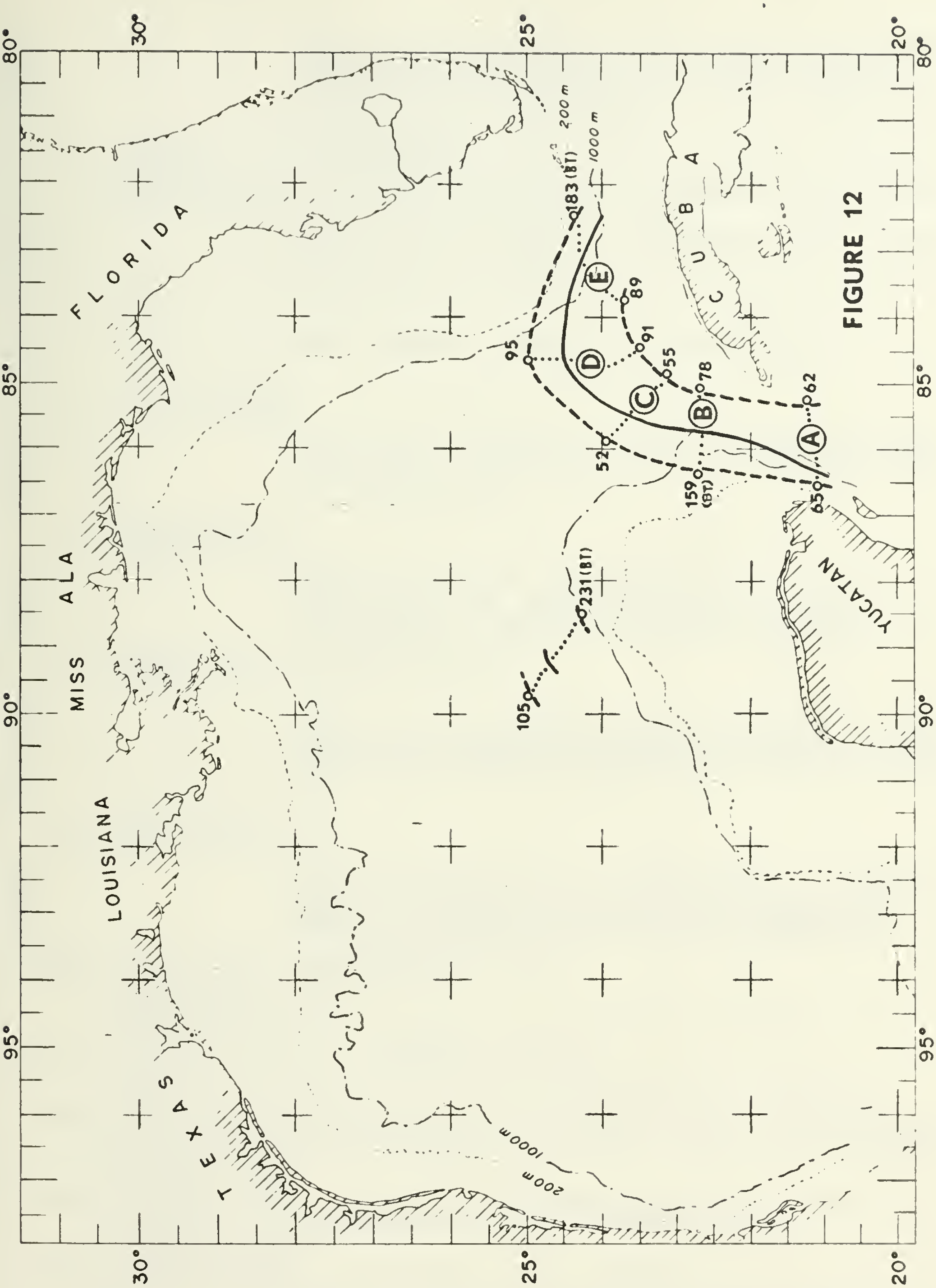
Dynamic Topography of the 200 Meter Surface
Relative to 1000 Meters (Cruise 67-A-6)

Figure 10



Dynamic Topography of the 500 Meter Surface
Relative to 1000 Meters (Cruise 67-A-6)

Figure 11



Location of Loop Current (Cruise 67-A-6)

Figure 12

```
C                 THIS PROGRAM COMPUTES GEOSTROPHIC VOLUME
C                 TRANSPORT AND VELOCITY OF WATER LAYERS,
C                 RELATIVE TO 1000 METERS,BETWEEN PAIRS OF
C                 HYDROGRAPHIC STATIONS
C
      IMPLICIT INTEGER*4(Z)
      REAL*4 LAT1,LAT2,LONG1,LONG2
      DIMENSION SVA1(19),SVA2(19),Z(19),V(19),DT(19),TQ(19),
     *SDD1(19),SDD2(19),D(19),DD(19)
C
C                 OMEGA IS THE ANGULAR ROTATION OF THE EARTH
C                 IN RADIANS/SECOND
C
      OMEGA=.729E-04
C
C                 FACT CONVERTS DEGREES TO RADIANS
C
      FACT=.017453
      F1=2.0*OMEGA
C
C                 READ IN THE VALUES OF THE STANDARD DEPTHS,
C                 IN METERS, FROM THE CHOSEN REFERENCE LEVEL
C                 TO THE SURFACE
C
      READ(5,45) Z
   45 FORMAT(19I4)
C
C                 READ IN STATION ONE;NUMBER(N1),LATITUDE
C                 IN DEGREES(XD) AND MINUTES(XM), AND
C                 LONGITUDE IN DEGREES(YD) AND MINUTES(YM)
C
      READ(5,40) N1,XD,XM,YD,YM
   40 FORMAT(I3,4F5.1)
C
C                 READ IN THE SPECIFIC VOLUME ANOMALY TIMES
C                 10E 05, AT STANDARD DEPTHS, FROM THE CHOSEN
C                 REFERENCE LEVEL TO THE SURFACE FOR STATION
C                 ONE
C
      READ(5,35) SVA1
   35 FORMAT(10F8.1)
C
C                 READ IN STATION TWO DATA(NUMBER,LATITUDE,
C                 LONGITUDE,SPECIFIC VOLUME ANOMALY) FROM THE
C                 CHOSEN REFERENCE LEVEL TO THE SURFACE
C
 1000 READ(5,40) N2,XXD,XXM,YYD,YYM
      IF(N2.EQ.0) GO TO 2000
      READ(5,35) SVA2
      WRITE(6,65)
   65 FORMAT('1',31X,'(CRUISE TITLE)')
      WRITE(6,70)
   70 FORMAT('+',35X,'(DASHES TO UNDERLINE THE TITLE)')
      WRITE(6,400)
  400 FORMAT('0','DEPTH',2X,'STATION',2X,'SUM OF DELTA-D''S'
     *,2X,'STATION',2X,'SUM OF DELTA-D''S',2X,'VEL OF SURF',
     *4X,'DELTA-T')
      WRITE(6,500)
  500 FORMAT(' ',1X,'(M)',4X,'NUMBER',4X,'(DYNAMIC-M)',6X,
     *'NUMBER',4X,'(DYNAMIC-M)',6X,'(CM/SEC)',4X,
     *'(SVERDRUPS)')
      WRITE(6,800)
  800 FORMAT('+','_____',2X,'_______',2X,'________________',
     *2X,'_______',2X,'________________',2X,'___________',
     *2X,'__________')
      WRITE(6,300) N1,N2
  300 FORMAT('0',9X,I3,24X,I3)
      SDD1(1)=0.0
      SDD2(1)=0.0
      DD(1)=0.0
      D(1)=0.0
      V(1)=0.0
```

```
      DT(1)=0.0
      TQ(1)=0.0
C
C                 THIS SECTION UTILIZES THE POSITIONS OF THE
C                 STATIONS TO COMPUTE THE ACTUAL DISTANCE
C                 BETWEEN THE STATIONS.  THE MEAN LATITUDE
C                 OF THE STATIONS IS USED TO CONVERT THE
C                 DIFFERENCE IN LONGITUDES TO TRUE DISTANCE.
C
      LAT1=XD+XM/60.0
      LAT2=XXD+XXM/60.0
C
C                 XDIST IS THE DISTANCE, IN METERS, FOR THE
C                 DIFFERENCE IN LATITUDE BETWEEN STATIONS
C
      XDIST=(LAT1-LAT2)*60.0*1852.0
C
C                 PHI IS THE MEAN LATITUDE OF THE TWO
C                 STATIONS CONVERTED TO RADIANS
C
      PHI=(LAT1+LAT2)/2.0*FACT
C
C                 FAC CONVERTS THE DIFFERENCE IN LONGITUDE
C                 TO DISTANCE IN METERS
C
      FAC=111415.13*COS(PHI)-94.55*COS(3.0*PHI)
      LONG1=YD+YM/60.0
      LONG2=YYD+YYM/60.0
      YDIST=(LONG1-LONG2)*FAC
C
C                 TDIST IS THE TRUE DISTANCE BETWEEN STATIONS
C
      TDIST=SQRT(XDIST**2+YDIST**2)
      SLAT=SIN(PHI)
C
C                 F IS THE CORIOLS PARAMETER
C
      F=F1*SLAT
      CONST=10.0/F
      WRITE(6,100) Z(1),SDD1(1),SDD2(1),V(1),DT(1)
  100 FORMAT('0',I4,15X,F7.4,20X,F7.4,8X,F10.5,3X,F8.4)
      DO 50 I=2,19
C
C                 'D' IS THE DYNAMIC HEIGHT BETWEEN TWO
C                 ISOBARIC SURFACES AT STATION ONE
C                 'DD' IS THE DYNAMIC HEIGHT BETWEEN TWO
C                 ISOBARIC SURFACES AT STATION TWO
C
      D(I)=(SVA1(I-1)+SVA1(I))/2.0*(Z(I-1)-Z(I))*1.0E-05
      DD(I)=(SVA2(I-1)+SVA2(I))/2.0*(Z(I-1)-Z(I))*1.0E-05
C
C                 SDD1 AND SDD2 ARE THE SUMS OF DYNAMIC
C                 HEIGHTS FOR STATIONS ONE AND TWO
C                 RESPECTIVELY WITH RESPECT TO 1000 METERS
C
      SDD1(I)=SDD1(I-1)+D(I)
      SDD2(I)=SDD2(I-1)+DD(I)
C
C                 'V' IS THE VELOCITY OF A WATER SURFACE
C                 WITH RESPECT TO THE CHOSEN REFERENCE LEVEL
C
      V(I)=(SDD1(I)-SDD2(I))*CONST/TDIST*1.0E 02
C
C                 'DT' IS THE TRANSPORT IN A LAYER BETWEEN
C                 TWO STATIONS WITH RESPECT TO A CHOSEN
C                 REFERENCE LEVEL, IN SVERDRUPS
C                 TQ=TRANSPORT BETWEEN THE SURFACE AND 1000
C                 METERS BETWEEN TWO STATIONS, IN SVERDRUPS
C                 T2=TRANSPORT BETWEEN THE SURFACE AND 200
C                 METERS BETWEEN TWO STATIONS, WITH RESPECT
C                 TO 1000 METERS, IN SVERDRUPS
C                 T5=TRANSPORT BETWEEN THE SURFACE AND 500
```

```
C                    METERS BETWEEN TWO STATIONS, WITH RESPECT
C                    TO 1000 METERS, IN SVERDRUPS
C
      DT(I)=(V(I-1)+V(I))/2.0*(Z(I-1)-Z(I))*TDIST*1.0E-02/1.
     *0E 06
      TQ(I)=TQ(I-1)+DT(I)
      WRITE(6,100) Z(I),SDD1(I),SDD2(I),V(I),DT(I)
   50 CONTINUE
      T2=TQ(19)-TQ(10)
      T5=TQ(19)-TQ(6)
      WRITE(6,600)
  600 FORMAT('0',TRANSP(0-200M)',3X,'TRANSP(0-500M)',3X,
     *'TRANSP(0-1000M)')
      WRITE(6,700)
  700 FORMAT(' ',1X,'(SVERDRUPS)',6X,'(SVERDRUPS)',7X,
     *'(SVERDRUPS)')
      WRITE(6,900)
  900 FORMAT('+','---------------',3X,'---------------',3X,
     *'---------------')
      WRITE(6,200) T2,T5,TQ(19)
  200 FORMAT('0',3X,F9.4,8X,F9.4,8X,F9.4)
      DO 60 J=1,19
      SVA1(J)=SVA2(J)
   60 CONTINUE
      N1=N2
      XD=XXD
      XM=XXM
      YD=YYD
      YM=YYM
      GO TO 1000
 2000 WRITE(6,30)
   30 FORMAT('1')
      STOP
      END
```

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ABSTRACT

To make comparisons to seven similar cruises, the geostrophic method of volume transport and velocity analysis was applied to ALAMINOS cruises 67-A-6 of 4 to 22 August 1967 and 68-A-2 of 13 February to 6 March 1968. An average velocity of 83 cm/sec and a volume transport of 27.5 Sverdrups was found in the Yucatan Channel in August and an average velocity of 79 cm/sec and a volume transport of 26.6 Sverdrups was found in the channel for February to March. A subsurface westward flow occurred in August along the southern coast of Cuba providing input into the Loop Current north of the Yucatan Channel. The Loop Current never crossed 25°N latitude. A cold ridge extended from the Florida shelf to the Campeche Bank.

An analysis of East-West volume transport in the central Gulf indicated a merging of east and west Gulf waters between $87^{\circ}50'$W and $89^{\circ}30'$W longitude for the MABEL TAYLOR cruise of 1932 and the ATLANTIS cruise of 1935. The GERONIMO cruise of February-March 1967 and cruise 68-A-2 indicated a merging of east and west Gulf waters between $89^{\circ}30'$W and $91^{\circ}00'$W longitude.

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